pennsylvania
DEPARTMENT OF ENVIRONMENTAL
PROTECTION

Commonwealth of Pennsylvania
Department of Environmental Protection
Ozone Exceptional Event Analysis
May 24-26, 2016

November 2017

Tom Wolf, Governor
Commonwealth of Pennsylvania

Patrick McDonnell, Secretary
Department of Environmental Protection

www.dep.pa.gov

This page intentionally left blank

Table of Contents

List of Figures

List of Tables

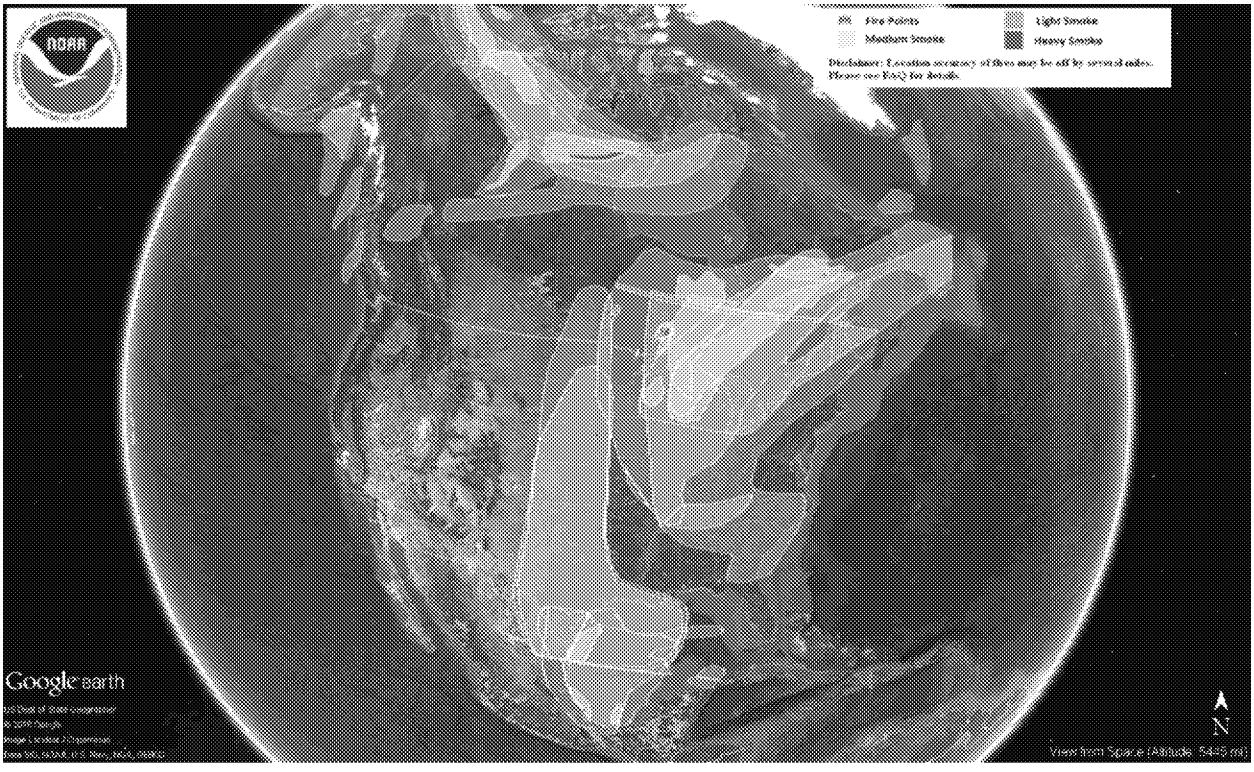
Overview of Pennsylvania's Exceptional Event Demonstration

Introduction

On May 24, 2016, Pennsylvania began to feel the effects of elevated ozone concentrations originating from the upper Midwest. This event lasted across Pennsylvania until May 26, 2016, impacting various ozone monitors as the air mass traveled from west to east across the Commonwealth.

After further analysis, the trajectory from which this ozone episode arrived across the Commonwealth was very unusual. After analyzing meteorological and photochemical processes across North America during this three-day period, it became very evident that an air mass from northwestern Canada (specifically from Fort McMurray, Alberta, Canada) had moved in across the northeastern US and impacted air quality from areas as far west as Wisconsin to as far east as Massachusetts. Figure 1 below displays the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) analysis of fire and smoke locations across North America on May 22, 2016.

Figure 1 – NOAA HMS Analysis of Fire and Smoke Locations on May 22, 2016



As required by the Exceptional Events Rule (40 CFR Part 50.14), the Department sent an email to U.S. EPA Region 3 on January 19, 2017 addressing the Department's intent to submit an exceptional events analysis, excluding ozone data from May 25, 2016 and May 26, 2016. After further evaluation, the Department is proposing to include May 24, 2016 as part of this

exceptional event analysis. In the email, the Department discussed such factors as the extent of smoke across North America while discussing back trajectories from areas of Pennsylvania that were impacted from the smoke. The Department also included an analysis of how this event impacted design value calculations at every ozone monitor in Pennsylvania.

Within this document, the Department will discuss the feasibility of excluding the May 24, May 25, and May 26, 2016 ozone data from a select group of monitors operated by the Department and the Philadelphia Air Management Services. This discussion will include an analysis of air quality data, including ozone and $PM_{2.5}$ speciation data, and meteorological data.

U.S. EPA Exceptional Event Guidance Overview

In October 2016, U.S. EPA released a revised Exceptional Event Rule (codified in 40 CFR Part 50.14). 40 CFR Part 50.14.b discusses the determinations that the U.S. EPA Regional Administrator can make on excluding data, including the following:

1.) Generally
2.) Fireworks displays
3.) Prescribed fires
4.) Wildfires
5.) High wind dust events
6.) Stratospheric intrusions
7.) Determinations with respect to event aggregation, multiple national ambient air quality standards for the same pollutant, and exclusion for 24-hour values for particulate matter
8.) Determinations with respect to the not reasonably controllable or preventable criterion.
9.) Mitigation plans.

This exceptional event analysis would be classified as being influenced by wildfires. Furthermore, the wildfire section goes on to state the following:

"The Administrator shall exclude data from use in determinations of exceedances and violations where a State demonstrates to the Administrator's satisfaction that emissions from wildfires caused a specific air pollution concentration in excess of one or more national ambient air quality standard at a particular air quality monitoring location and otherwise satisfies the requirements of this section. Provided the Administrator determines that there is no compelling evidence to the contrary in the record, the Administrator will determine every wildfire occurring predominantly on wildland to have met the requirements identified in paragraph (c)(3)(iv)(D) of this section regarding the not reasonably controllable or preventable criterion."

The Department intends to follow the guidance outlined within the Exceptional Event Rule to properly assess the impact of the Fort McMurray wildfires on ozone concentrations across the Commonwealth.

Regulatory Significance and NAAQS Attainment Impact

When the Exceptional Event Rule was released, U.S. EPA also announced dates by which state/local organizations had to submit their exceptional event analyses. For 2016 ozone data that was being used for consideration in U.S. EPA's 2015 ozone NAAQS nonattainment designations, the deadline for submittal was May 31, 2017. As a result, the Department completed an analysis of ozone monitors within the Commonwealth that were impacted from May 24 to May 26. Table 1 below displays the monitors that the Department feels an exceptional event exclusion could have on regulatory significance today as it relates to the designation process for the 2015 ozone standard. In addition, Table 1 below illustrates the impact that the May 24, May 25 and May 26 daily maximum 8-hour ozone concentrations had on the current 2016 ozone design values for these respective monitors. In addition, the rank (1 is representative of the first high, 2 is representative of the second high, and so on…) is provided to show the overall impact of the Fort McMurray fires on the calculation of the fourth highest daily maximum 8-hour ozone concentrations across the Commonwealth. The Department has already flagged this data in U.S. EPA's Air Quality System database for possible exceptional event exclusion.

The Department is also requesting that U.S. EPA consider the ozone monitors highlighted in Table 2 for exceptional event exclusion for the May 24 to May 26, 2016 period. Although the monitors outlined in Table 2 do not have regulatory significance as it relates to the designations for the 2015 ozone standard, the Department is concerned with the impact that the Fort McMurray wildfires could potentially have on these monitors as it relates to future year design value calculations for 2017 and 2018.

From May 24 to May 26, 2016, forty-three Department and Philadelphia Air Management Services (AMS) monitors monitored at least one maximum 8-hour ozone concentration that was one of its respective fourth highest during 2016. Monitors across western and northern Pennsylvania were impacted first on May 24 as the air mass from the fires made its way from west to east across the Commonwealth. On May 25, much of the Commonwealth monitored their highest daily maximum 8-hour ozone concentrations for 2016. By May 26, only far eastern and southern Pennsylvania continued to be impacted by the elevated ozone concentrations.

Table 1 – Pennsylvania Monitors Requested for Exceptional Event Exclusion

AQS Code	Site Name	4th Maximum 8-Hour Ozone Concentration (ppb)			2014-2016 Ozone Design Value (ppb)	Maximum 8-Hr Ozone Concentration & Rank (ppb) for Exceptional Event Days						Ozone Design Value Excluding Exceptional Event Data	
						5/24/2016		5/25/2016		5/26/2016		2016 4th Max (ppb)	2014-2016 Ozone Design Value (ppb)
		2014	2015	2016		Max	Rank	Max	Rank	Max	Rank		
420110011	Reading Airport	68	71	75	71	57	29	79	1	76	3	71	70
420750100	Lebanon	67	74	72	71	57	29	76	2	72	4	70	70
420910013	Norristown	72	73	73	72	53	55	82	1	74	3	67	70

* - Rank 1 through 4 is highlighted in red.

** - Ozone Design Values in exceedance of the 2015 ozone NAAQS are highlighted in red.

Table 2 – Additional Pennsylvania Monitors Requested for Exceptional Event Exclusion

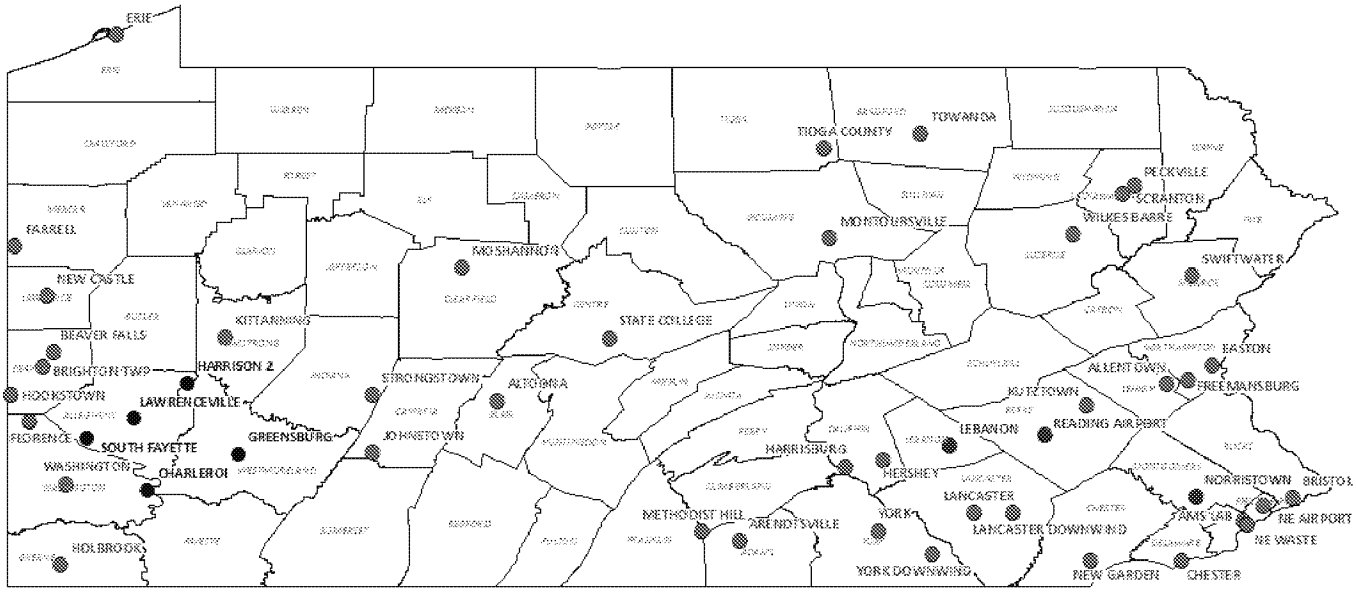
AQS Code	Site Name	4th Maximum 8-Hour Ozone Concentration (ppb)			2014-2016 Ozone Design Value (ppb)	Maximum 8-Hr Ozone Concentration & Rank (ppb) for Exceptional Event Days						Ozone Design Value Excluding Exceptional Event Data	
						5/24/2016		5/25/2016		5/26/2016		2016 4th Max (ppb)	2014-2016 Ozone Design Value (ppb)
		2014	2015	2016		Max	Rank	Max	Rank	Max	Rank		
420010001	Arendtsville	-	65	73	69	70	6	76	1	65	14	72	68
420050001	Kittanning	68	70	73	70	73	4	75	2	62	17	70	69
420070002	Hookstown	69	70	71	70	68	7	71	4	54	61	69	69
420070005	Brighton Twp	70	67	68	68	67	6	70	2	49	78	68	68
420070014	Beaver Falls	66	63	68	65	69	3	72	1	51	58	66	65
420110006	Kutztown	63	66	70	66	54	24	73	2	70	4	68	65
420130801	Altoona	60	69	62	63	62	7	71	2	53	31	62	63
420150011	Towanda	51	58	60	56	62	2	69	1	60	4	57	55
420170012	Bristol	71	82	80	77	52	64	84	1	81	3	75	76
420210011	Johnstown	60	65	64	63	64	4	64	5	56	28	63	62
420270100	State College	63	64	63	63	58	18	77	1	59	15	63	63
420290100	New Garden	71	68	80	73	58	32	80	4	73	6	75	71
420334000	Moshannon	60	68	66	64	63	8	76	1	63	9	66	64
420430401	Harrisburg	63	68	68	66	55	28	69	2	58	12	64	65
420431100	Hershey	63	68	70	67	57	28	75	1	66	6	67	66
420450002	Chester	73	74	71	72	54	49	80	2	71	4	70	72
420490003	Erie	65	66	67	66	70	3	79	1	67	4	65	65
420550001	Methodist Hill	63	59	59	60	56	9	61	2	55	12	58	60
420590002	Holbrook	65	71	67	67	60	19	67	4	48	85	67	67
420630004	Strongstown	68	73	71	70	71	3	72	2	58	27	67	69
420690101	Peckville	61	69	71	67	63	16	79	1	73	3	68	66
420692006	Scranton	60	68	66	64	57	18	74	1	67	2	65	64
420710007	Lancaster	66	71	71	69	59	27	81	1	80	2	66	67
420710012	Lancaster Downwind	63	70	67	66	53	37	73	1	68	2	62	65
420730015	New Castle	68	69	68	68	67	5	68	2	47	78	66	67
420770004	Allentown	68	70	73	70	-	-	-	-	73	4	71	69
420791101	Wilkes Barre	60	67	66	64	61	14	76	1	65	6	65	64
420810100	Montoursville	62	65	65	64	63	5	73	1	65	3	63	63
420850100	Farrell	71	66	70	69	74	2	81	1	52	60	69	68
420890002	Swiftwater	60	67	70	65	60	19	82	1	72	3	68	65
420950025	Freemansburg	67	70	75	70	57	38	82	2	75	3	72	69
420958000	Easton	66	67	74	69	56	21	80	2	74	4	69	67
421010004	AMS Laboratory	58	57	69	61	42	92	69	4	59	13	67	60
421010024	Northeast Airport	72	79	80	77	53	75	84	1	79	5	78	76
421010048	Northeast Waste	68	78	76	74	47	91	77	3	71	6	75	73
421174000	Tioga County	58	65	68	63	73	2	74	1	68	4	63	62
421250200	Washington	64	69	64	65	58	16	65	2	49	59	64	65
421255001	Florence	64	71	70	68	64	13	72	2	56	43	68	67
421330008	York	63	68	69	66	56	36	71	3	67	5	67	66
421330011	York Downwind	63	74	73	70	58	37	75	3	80	1	69	68

* - Rank 1 through 4 is highlighted in red.

** - Ozone Design Values in exceedance of the 2015 ozone NAAQS is highlighted in red.

Figure 2 displays a map of all 53 ozone monitors outlined above. Ozone monitors selected for additional analysis as it relates to exceptional event exclusion are highlighted in red (Table 1 monitors) and blue (Table 2 monitors).

Figure 2 – Pennsylvania Ozone Monitoring Network



Summary of Findings

The Department used multiple techniques to demonstrate that the Fort McMurray fires had an impact on ozone formation across the Commonwealth from May 24 to May 26, 2016. As part of this exceptional event demonstration, the Department to determine the following:

1.) There was a relationship between the smoke and the frequency of daily 8-hour ozone exceedances across the Commonwealth.
2.) The Fort McMurray fires were considered a natural event.
3.) The smoke event in question were not reasonably preventable and are unlikely to reoccur.

Within its analysis, the Department used air monitoring and meteorological data to support its argument that the Fort McMurray fires caused ozone exceedances across the Commonwealth. Key findings that were included as part of this analysis include the following:

1.) Smoke induced ozone was generated upstream (across the Great Lakes) of Pennsylvania and then transported south and east across the Commonwealth.
2.) The ozone concentrations experienced from May 24 to May 26, 2016 were abnormally high for May; ozone concentrations at many locales were in the upper tier (top 1%) of historical May ozone concentrations.
3.) Fine particulates (PM2.5) and speciated PM2.5 were elevated during the same period.
4.) Meteorological conditions (at the surface and aloft) were favorable for transport of smoke from Canada to the northeastern US.
5.) Satellite imagery displays the presence of smoke in air across the northeastern US during the same time as the ozone concentrations peaked.
6.) Additional analyses, such as Q/d, similar day analysis and photochemical modeling demonstrates the smoke's influence on ozone formation across the Commonwealth.

In addition to what is presented above, the timing of the May 24 to May 26, 2016 high daily 8-hour ozone concentrations (occurring in May as opposed to peak ozone season in July) is also discussed within this demonstration. The Department considered the typical emission profile of a daily 8-hour ozone exceedances across the Commonwealth. The characteristics of this high ozone event are unique in that it is not the same as the emission and meteorological profiles that normally contribute to high ozone concentrations during the peak of summer across the Commonwealth.

Overall, the Department's analysis strongly supports that all forty-three monitors outlined in Table 1 and Table 2 above had daily 8-hour ozone concentrations that were impacted from smoke from the Fort McMurray fires. The Department's exceptional event demonstration, which is summarized above, is detailed below in the following sections.

A Conceptual Model – Fort McMurray Fire's Influence on Ozone Formation in Pennsylvania from May 24 to May 26, 2016

Typical Summertime Ozone Formation – Emission Discussion

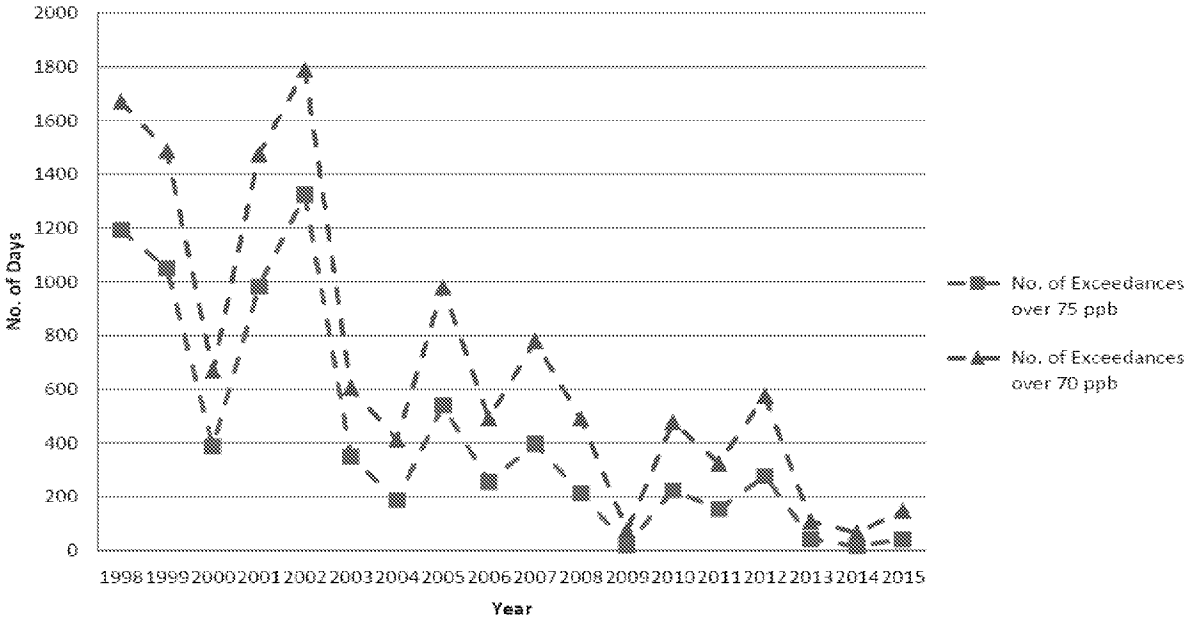
The highest ozone concentrations across the Mid-Atlantic generally occur during the summer season. There are several reasons this is the case:

1.) Ozone is a photochemical pollutant, which means sunlight is a requisite for formation (in the presence of VOCs and a combination of regional and local anthropogenic NOx sources)
2.) The longest day length occurs during the Summer solstice (around June 21) each year
3.) The hottest afternoon peak temperatures occur during the Summer season.

Peak ozone concentrations are not only a factor of existing meteorological conditions; peak ozone concentrations are reliant on regional and local emission loading on any given day. Pennsylvania is a part of the Ozone Transport Region (OTR). The primary sources of NOx in Pennsylvania are point sources (such as electric generating units) and mobile sources (such as vehicular and truck emissions). Historically, the main ozone problems in the Commonwealth have been downwind of the major metropolitan areas as a result of long-range transport (from point source emissions across the Ohio Valley) and short-range transport (from local point and mobile sources within the metropolitan area).

Within the last fifteen years, NOx control programs such as the NOx SIP Call and other interstate transport rules (Clean Air Interstate Rule (CAIR) and Cross-State Air Pollution Rule (CSAPR)) have had a positive impact on ozone formation across the OTR. The decline in NOx emissions across the US has led to a decline in the number of nonattainment areas (even with the tightening of the ozone standard in 2008 and 2015), a decline in the total number of annual ozone exceedances and a decline in the annual peak ozone concentrations. Figure 3 on the following page illustrates the trend in ozone exceedances from 1998 to 2015.

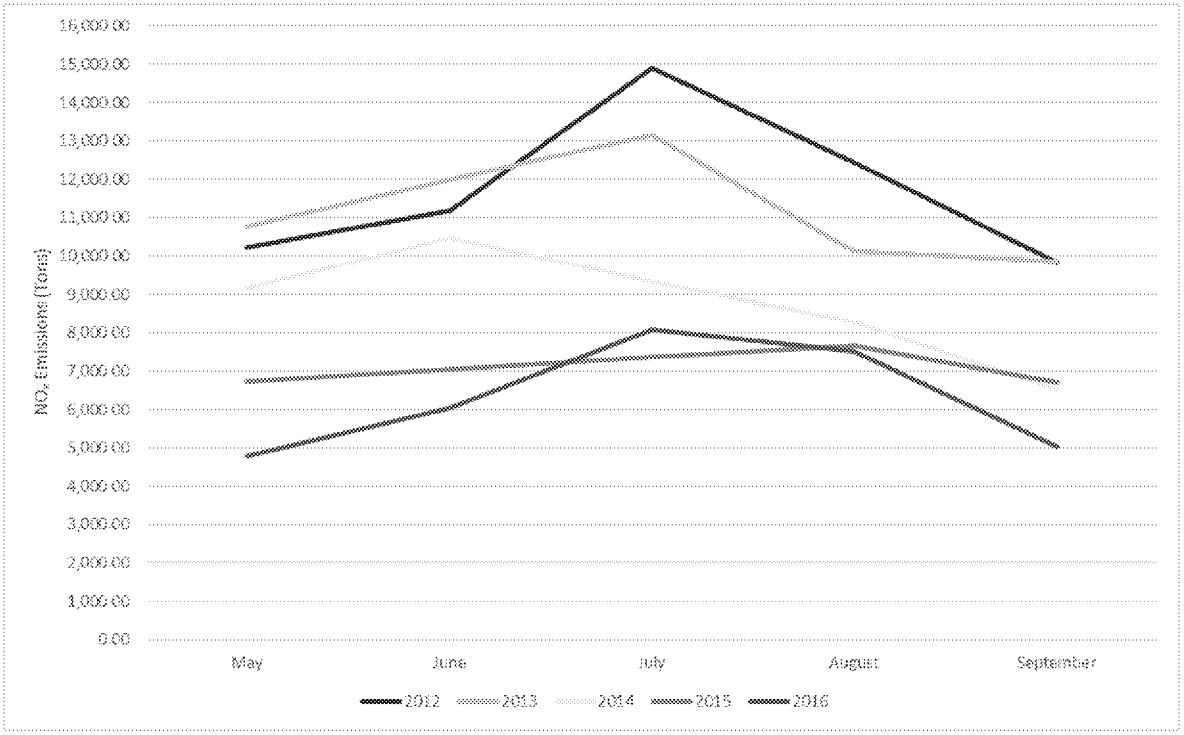
Figure 3 – Trend in Number of Ozone Exceedances in Pennsylvania (1998-2015)



The red line indicates the total number of ozone exceedances with respect to the 2008 ozone standard (above 75 ppb) that occurred in Pennsylvania, whereas the blue line indicates the total number of ozone exceedances with respect to the 2015 ozone standard (above 70 ppb). There are two significant downward step functions on the graph since the 1998 to 2002 period: the 2003 to 2008 period (likely due to the NOx SIP call, which was first implemented in 2003) and the 2009 to 2013 period (likely due to the implementation of CAIR/CSAPR, which began in 2009).

The largest change in emissions in the last five years (from 2012 to 2016) occurred in the EGU sector. Figure 4 on the following page displays the trend in the NOx emissions reported to U.S. EPA's Clean Air Markets Division (CAMD) during the summer months from 2012 to 2016.

Figure 4 – Trend in CAMD NOx Emissions Over Last Five Year (May through September)



Overall, from 2012 to 2016 there has been a decline in the amount of NOx emissions in Pennsylvania. NOx emissions generally peak in July most likely due to the electricity demand in the EGU sector. On average, July sees the hottest temperatures which causes a demand for air conditioning. More specifically, May's NOx emissions were the lowest of the 5-year period (approximately 44% of the peak NOx emissions in 2013). So even though May 2016's NOx emissions were at a 5-year low, the May 24 to May 26 period saw some of the highest peak 8-hour ozone concentrations during the 5-year period.

Typical Summertime Ozone Formation – Meteorological Discussion

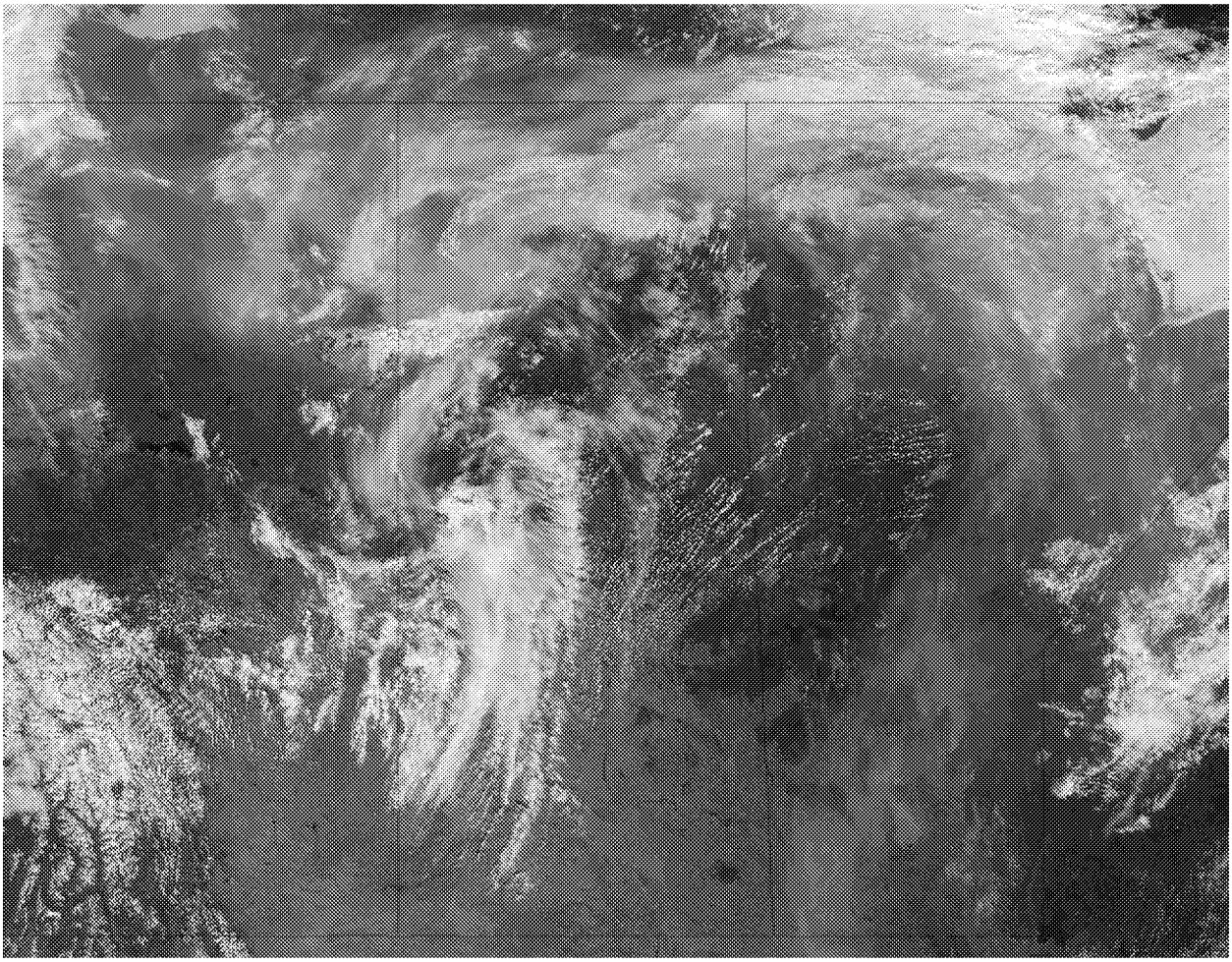
Over the summer, ozone formation generally peaks during July as a result of the long day length coupled with historically the hottest temperatures. Ozone exceedances can occur in April and September as well when the meteorological conditions and transport environment coincide positively with one another. Peak ozone concentrations generally occur under the presence of the Bermuda High (an area of high pressure centered across the western Atlantic near Bermuda). If the high remains centered over Bermuda, the clockwise rotation around the high will generally steer the prevailing wind flow out of the west, southwest. From time to time, the Bermuda High can build west across the eastern US and therefore change the steering flow across the Commonwealth. Under these circumstances, the flow will turn more westerly, allowing transport of emissions (including NOx from EGUs) from the Ohio Valley and midwestern US.

In addition to synoptic meteorological features such as the Bermuda High, more mesoscale features can develop, especially to the east of the Appalachian Mountains. A phenomenon known as the lee side trough can develop thanks to weak westerly flow over the Appalachians leading to compressional heating in the lee of the mountain. This lee trough generally sets up over the I-95 corridor. The lee trough leads to convergence at the surface and therefore an increase in ozone concentrations. Across Pennsylvania, this phenomenon generally impacts ozone development across the Philadelphia metropolitan area. Overall, the typical pattern that leads to high ozone formation across the Commonwealth is due to a combination of meteorological and manmade emissions.

Fort McMurray Fire Discussion

During the entire month of May 2016 and June 2016, the wildfires that burned in and around Fort McMurray, Alberta, Canada encompassed upwards of 1,500,000 acres of land. As provided by NASA, Figure 5 below displays MODIS satellite imagery from May 17, 2016 across southwestern Canada. Specifically, the MODIS imagery emphasizes the location of the Fort McMurray fires with respect to cloud cover and smoke plume extent. The Fort McMurray fires, highlighted in red below, were analyzed by MODIS's thermal bands.

Figure 5 – NASA MODIS Imagery of the Fort McMurray Fires on May 17, 2016

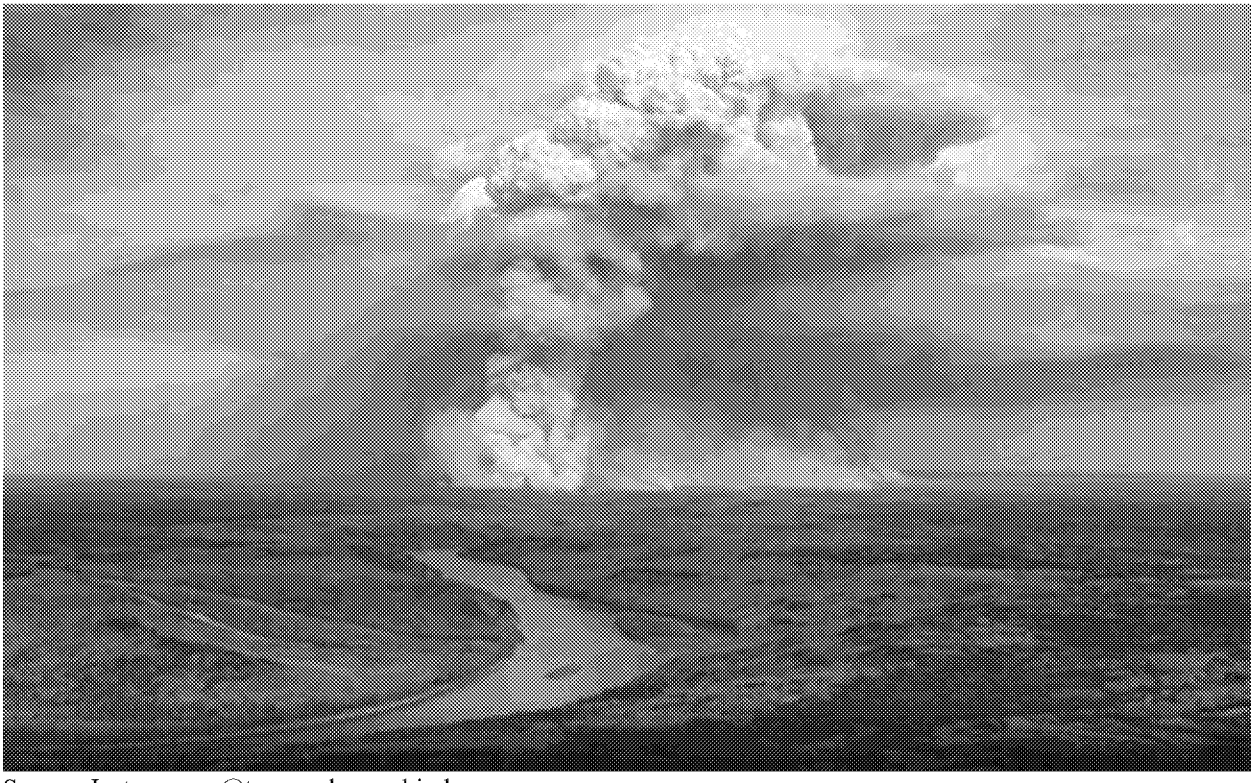


Source: https://www.nasa.gov/feature/goddard/2016/nasa-satellites-image-fort-mcmurray-fires-day-and-night

The Fort McMurray fires were covered by various news agencies across the world. On May 6, 2016, an article in the Washington Post highlighted that smoke from the Fort McMurray fires had infiltrated the southeastern US. The article goes on to state that the smoke traveled down to the Gulf Coast due to meteorological factors such as upper level winds transporting the smoke southward. Later in May, a Weather Channel article discussed the impact that Fort McMurray wildfires were having on Europe. Using NASA's Aerosol Index as a tool, the Weather Channel tracked the transport of smoke (aerosols) from western Canada eastward across the northern

Atlantic and into western Europe. Figure 6 below illustrates how high the plumes of smoke rose into the atmosphere and how it was being transported downwind.

Figure 6 – Aerial Photo of Fort McMurray Fire



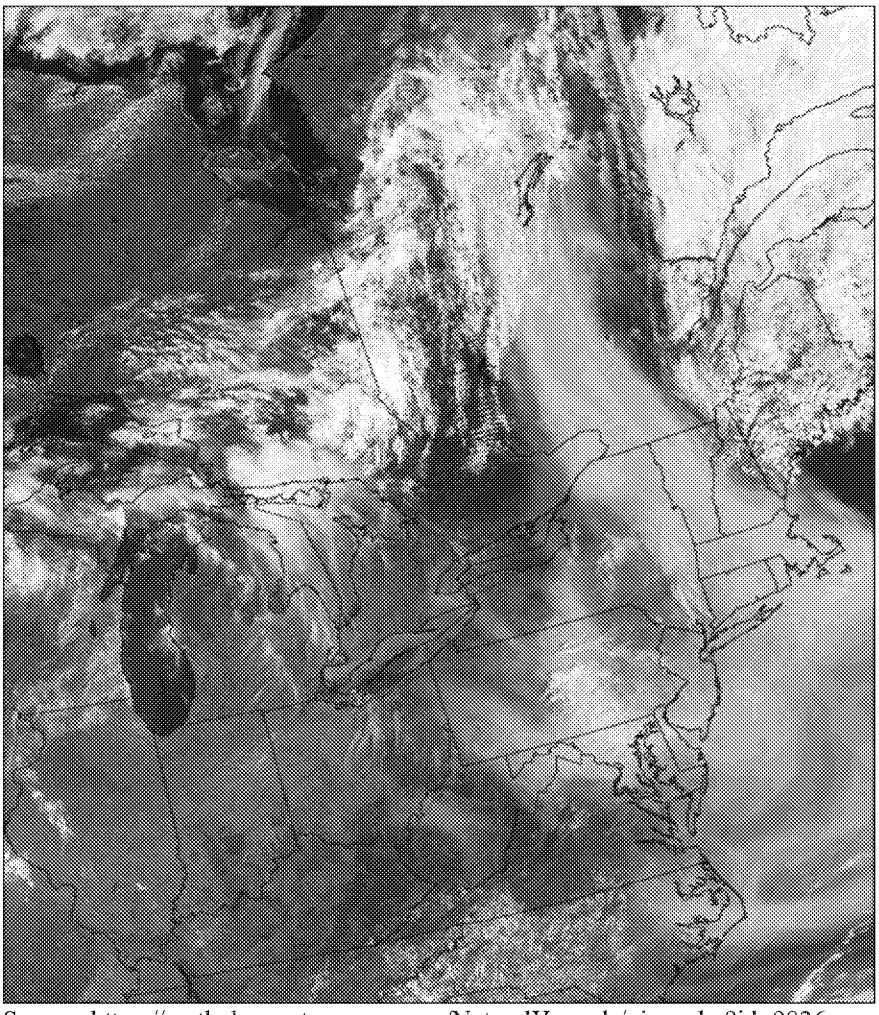
Source: Instagram - @tamarackaspenbirch

By July 6, 2016, the fire was declared to be under control. It was estimated that 2,400 building were destroyed because of the fire. In addition, direct and indirect costs associated with the fire were estimated to be in the $9.5 billion range.

Fort McMurray Fire Discussion – Conceptual Model of Ozone Formation

The impact from wildfire smoke on ozone concentrations has been studied since the early 2000s. In fact, the northeastern US was impacted by wildfire smoke as far back as July 2002, when forest fires across eastern Canada advected southward across the northeastern US. Figure 7 on the following page displays the satellite data which illustrates the impact of the smoke plume's across the northeastern US. Within Figure 7, the red shaded areas indicate the hot spots as evaluated by the satellite while the brownish area indicates the location of the smoke plume.

Figure 7 – MODIS Satellite Imagery of Northeastern US – July 7, 2002



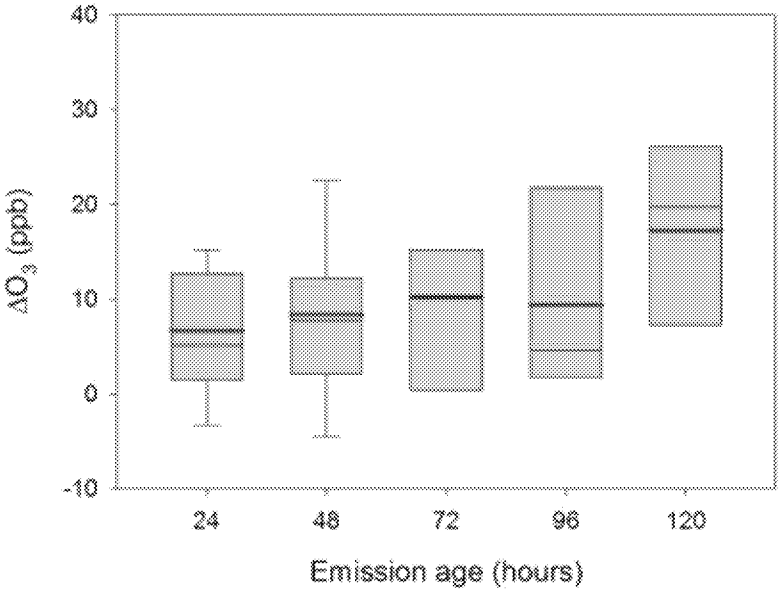
Source: https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=9826

At the time, numerous states that were impacted from the smoke filed for exceptional event exclusions for ozone and $PM_{2.5}$. Many of the $PM_{2.5}$ levels peaked on July 7, 2002 as the thickest part of the plume moved southward across the New England and northern Mid-Atlantic states. Ozone concentrations peaked in the days after the smoke shifted its way east into the Atlantic Ocean. Most recently, Joel Dreessen of the Maryland Department of the Environment wrote an article addressing the impact of forest fires originating in Saskatchewan, Canada in May 2015 on ozone concentrations across Maryland. One of the key points of Mr. Dreessen's work was determining that an aging smoke plume (as it is projected downwind from its source) contributed to an increase in ozone concentrations across Maryland. The ozone was generated upwind from Maryland and then advected into Maryland due to the prevailing meteorological pattern at the time.

Mr. Dreessen's analysis also hypothesized that once the smoke, which is rich in volatile organic compounds (VOC) from the burning fire, interacted with anthropogenic nitrogen oxide (NOx) sources, ozone production began. Coupled with prevailing upper level meteorological conditions, this ozone enhanced environment was able to be transported long distances as either

ozone or ozone reservoir species. In the May 2015 case, Mr. Dreessen illustrated that it took over 24 hours of aging for ozone to reach 70 parts per billion. Mr. Dreessen's work outlining delays in ozone production due to airmass aging is similar to those results represented in other studies (namely, D. Putero, et. al's work presented in the January 2014 publication of Environmental Pollution). As illustrated below in Figure 8 below and extrapolated from D. Putero's January 2014 Environmental Pollution article, D. Putero was able to display the relationship of the change in ozone concentrations with respect to the aging of the smoke airmass.

Figure 8 – Change in Ozone Concentrations with Respect to Smoke Plume Age



Fort McMurray Fire Meteorological Discussion – Overview

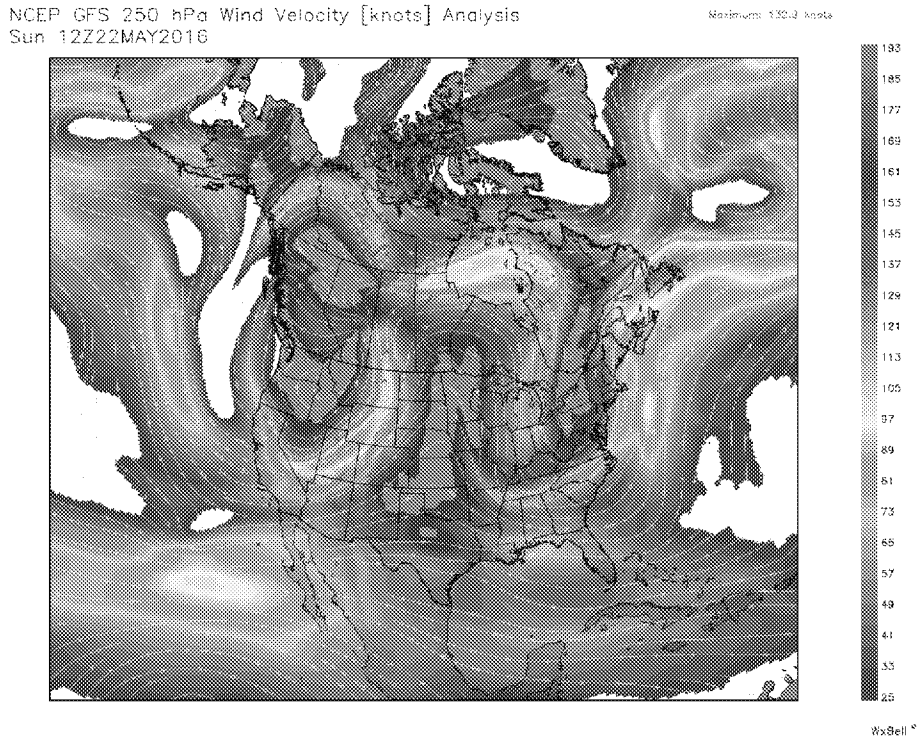
The meteorological pattern across southern Canada and the northern US on May 24 to May 26, 2016 played a crucial role in the transport of smoke from the Fort McMurray wildfires southeast across Canada and into the northeastern US. Starting on May 20, smoke from the Fort McMurray fires began to make their way into US by way of the northern Plains. On May 23 and May 24, smoke from the forest fires shifted east over the Great Lakes, Ohio Valley and western Pennsylvania region. By the end of the event (May 25 to May 27 time frame), the smoke traversed the northeastern US on its way toward the Atlantic Ocean.

The path the smoke traveled to produce ozone and to advect the elevated ozone concentrations south and east across the northeastern US was not indicative of the weather conditions that the Commonwealth experiences during "normal" enhanced ozone events. In the following sections, the upper air and surface meteorological conditions that contributed to the smoke associated with the Fort McMurray fires to be transported into the northeastern US will be discussed.

Fort McMurray Fire Meteorological Discussion – Upper Air Analysis

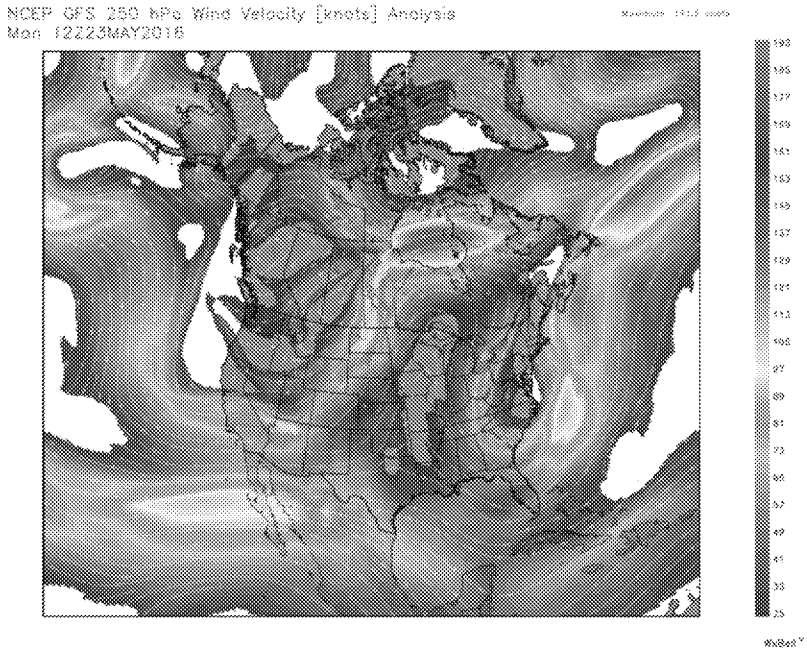
Historical upper air meteorological analysis data can be used to study the transport mechanism of air masses across North America. A reanalysis of the meteorological conditions that occurred on May 22 to May 26 was completed by Weatherbell Analytics, Inc (the Department owns a subscription to Weatherbell Analytics meteorological model data). Figures 9 to 13 display the meteorological conditions that were present on May 22 to May 26 at 250 mb (250 mb is indicative of the jet stream location). The jet stream drives the weather patterns across the continental US. In this case, smoke, from western Canada, was ejected into the northeastern US.

Figure 9 – 250 mb Wind Pattern on May 22, 2016 at 8 AM EDT



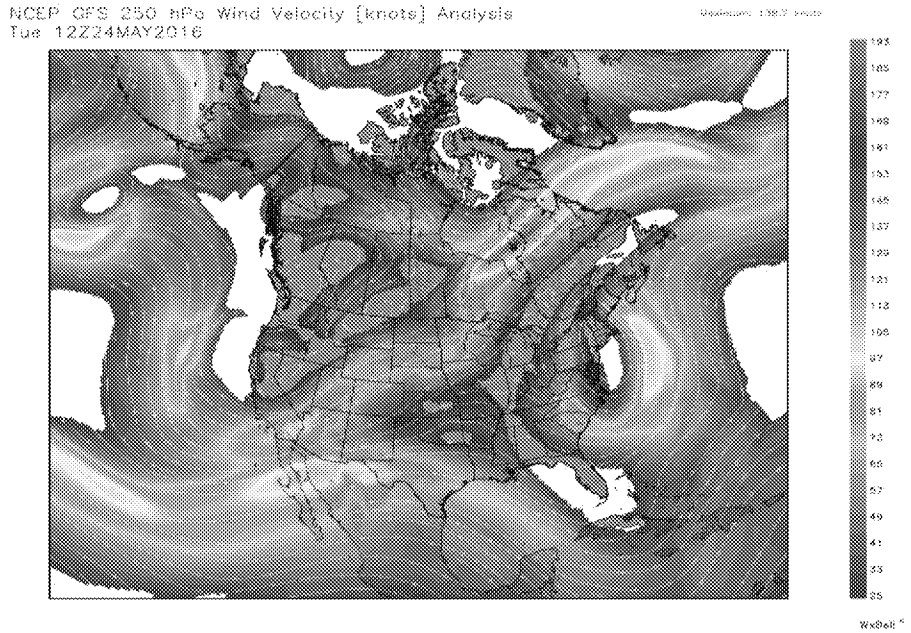
On May 22, the US was under the classic omega (Ω) block pattern (a trough, or dip in the jet stream, across the western and eastern US and a ridge, or rise in the jet stream, across the central US). This pattern allowed above normal temperatures to persist over the Plains states while cool air persisted across the northeastern US.

Figure 10 – 250 mb Wind Pattern on May 23, 2016 at 8 AM EDT



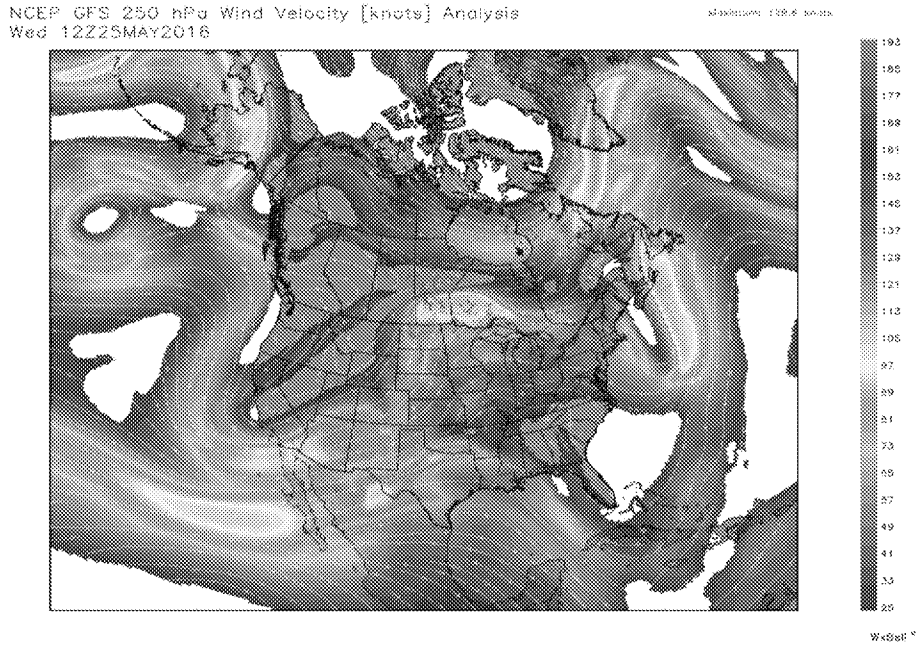
On May 23, the ridge that was across the central US on May 22 began to shift east as the trough remained situated across the eastern US. The upper level flow began to shift the transport pattern of weather from the northcentral US into the western Great Lakes region.

Figure 11 – 250 mb Wind Pattern on May 24, 2016 at 8 AM EDT



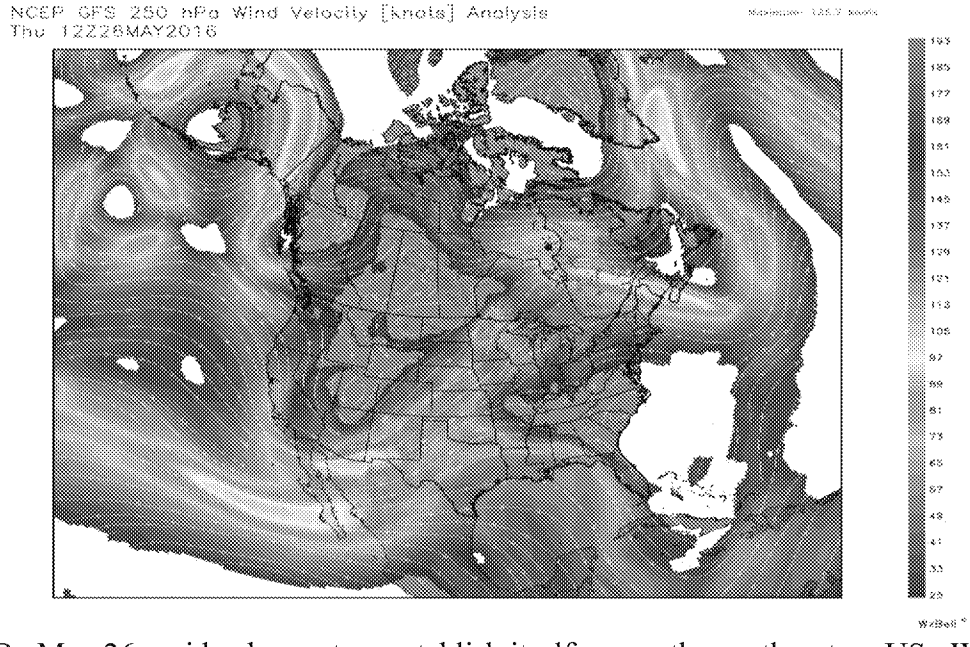
By May 24, the ridge that migrated east over the Ohio Valley on May 23 began to weaken. At the same time, a new upper level low formed just east of the New Jersey coastline. This shift in the weather pattern allowed the air mass that was over the western Great Lakes to begin to dip south and east across the Ohio Valley and western PA.

Figure 12 – 250 mb Wind Pattern on May 25, 2016 at 8 AM EDT



On May 25, the cutoff low that was off the New Jersey coastline on May 24 began to weaken and shift northeast. This transition allowed the flow to turn more zonal (west to east flow), forcing the air mass that was across the Ohio Valley and western PA on May 24 to travel eastward across Pennsylvania.

Figure 13 – 250 mb Wind Pattern on May 26, 2016 at 8 AM EDT



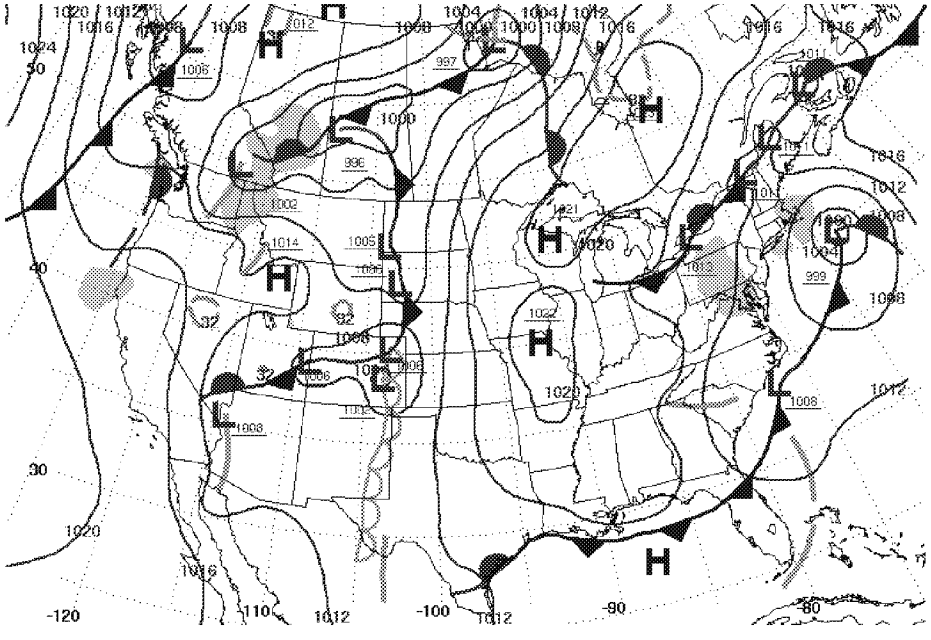
By May 26, a ridge began to reestablish itself across the southeastern US. Westerly, northwesterly flow persisted along the northern side of the ridge, forcing the air mass to continue its eastward trajectory across the Commonwealth.

As demonstrated in the five previous figures, the upper level winds, which steer the weather patterns across the world, were conducive to funneling smoke that was aloft south and east across northcentral US into the northeastern US from western Canada. Even though the upper level meteorology was favorable for such long-range transport to occur, the smoke that resided in the upper layers of the atmosphere still needed to have a meteorological mechanism to mix down to the surface. The Surface Analysis section below will outline the mechanism that allowed the air to sink from aloft toward the surface.

Fort McMurray Fire Meteorological Discussion – Surface Analysis

As outlined in the Upper Air Analysis section above, the upper air wind flow was conducive for a western Canadian air mass (that was aloft in the atmosphere) to be transported toward the northeastern US. The corresponding surface meteorological conditions were conducive as well. A surface analysis of the meteorological conditions that occurred on May 22 to May 26 was completed by NOAA. Images found in Figures 14 to 19 were generated from the NOAA Daily Weather Map website (http://www.wpc.ncep.noaa.gov/dailywxmap/). Figures 14 to 19 display the meteorological conditions that were present on May 22 to May 26 at the surface at 8 AM (the maps are labeled as 7 AM Eastern Standard Time (EST)… 7 AM EST equates to 8 AM Eastern Daylight Savings Time (EDT)). During these five days, the location of the smoke aloft coincided with the location of an area of high pressure (the big blue H on the maps below). In this case, smoke, which was aloft, could sink toward the surface.

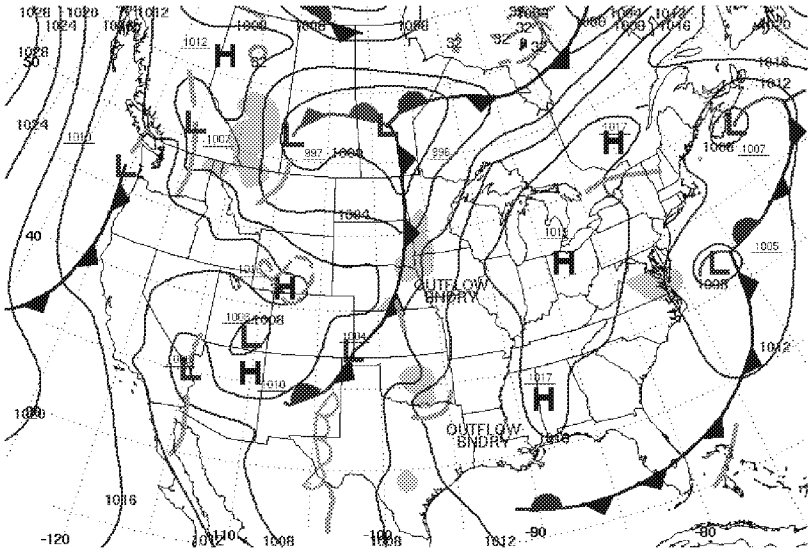
Figure 14 – NOAA Surface Analysis on May 22, 2016 at 8 AM EDT



Surface Weather Map at 7:00 A.M. E.S.T.

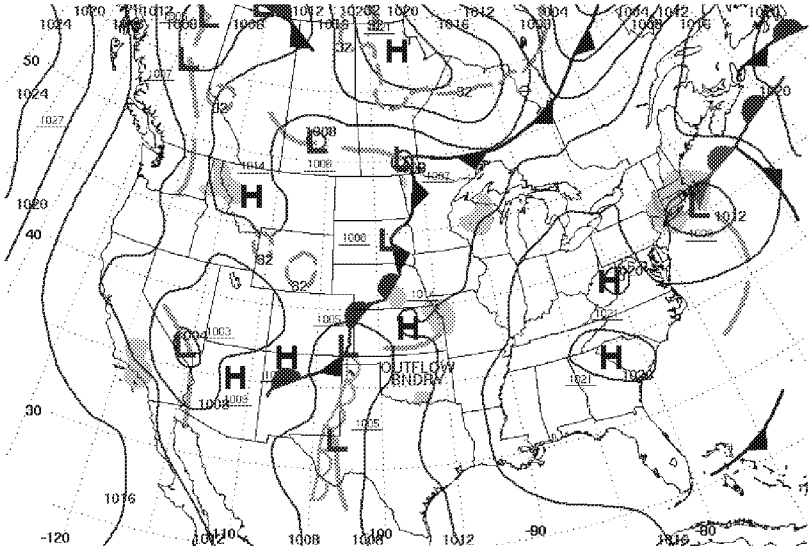
On May 22, an area of high pressure resided across the midwestern US. At the same time, a storm system impacted the northeastern US and provided rain across portions of the Mid-Atlantic. The clockwise flow around the high helped to steer the winds out of the surface out of the north and west across the Great Lakes region.

Figure 15 – NOAA Surface Analysis on May 23, 2016 at 8 AM EDT



On May 23, the area of high pressure, which was over the midwestern US on May 22, began to move east and over the Ohio Valley / eastern Great Lakes. At the same time, a storm system continued to drive rain showers into portions of the central Mid-Atlantic states. Like on May 22, the clockwise flow around the high transported flow from the north and west across the Great Lakes and into the northern Mid-Atlantic.

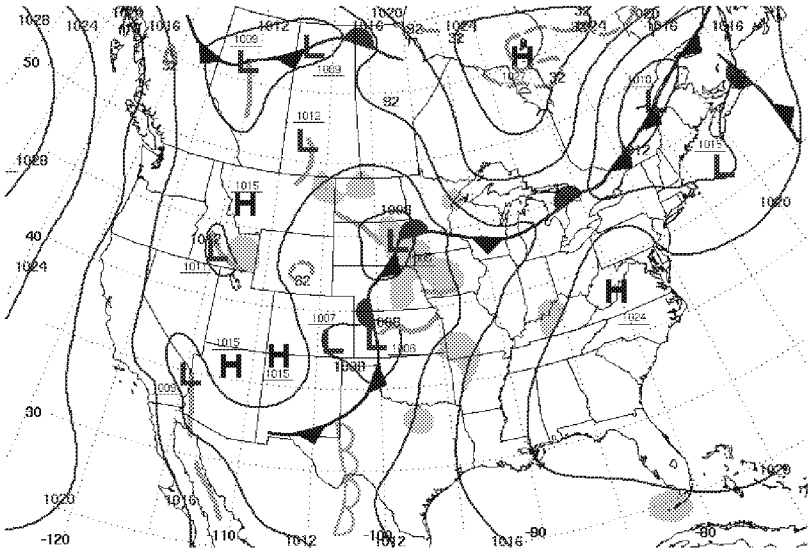
Figure 16 – NOAA Surface Analysis on May 24, 2016 at 8 AM EDT



On May 24, the area of high pressure, which moved in over the Ohio Valley / Great Lakes region on May 23, shifted further east and along the eastern US. The movement of the high drove the storm system, which plagued the Mid-Atlantic with rain for on May 22 and May 23,

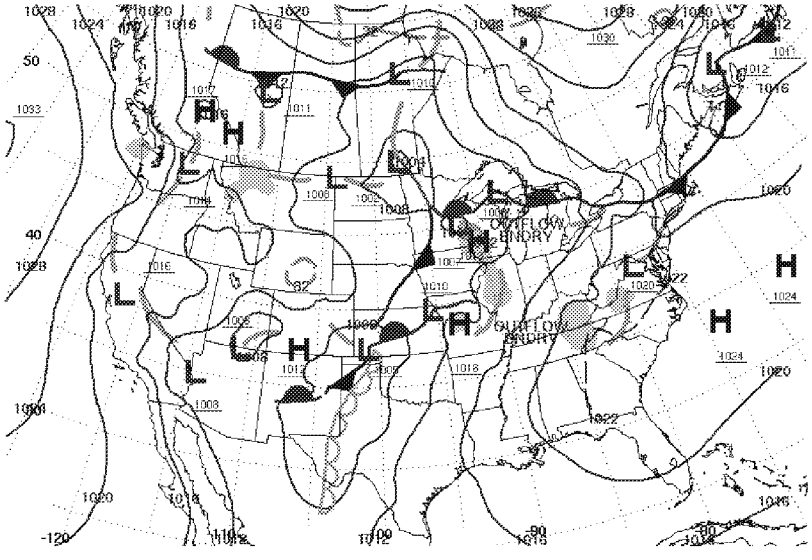
northeastward across the New England coastline. At the same time, the flow at the surface continued to funnel in from the north and west (from the Great Lakes / northern Ohio Valley into northwestern PA).

Figure 17 – NOAA Surface Analysis on May 25, 2016 at 8 AM EDT



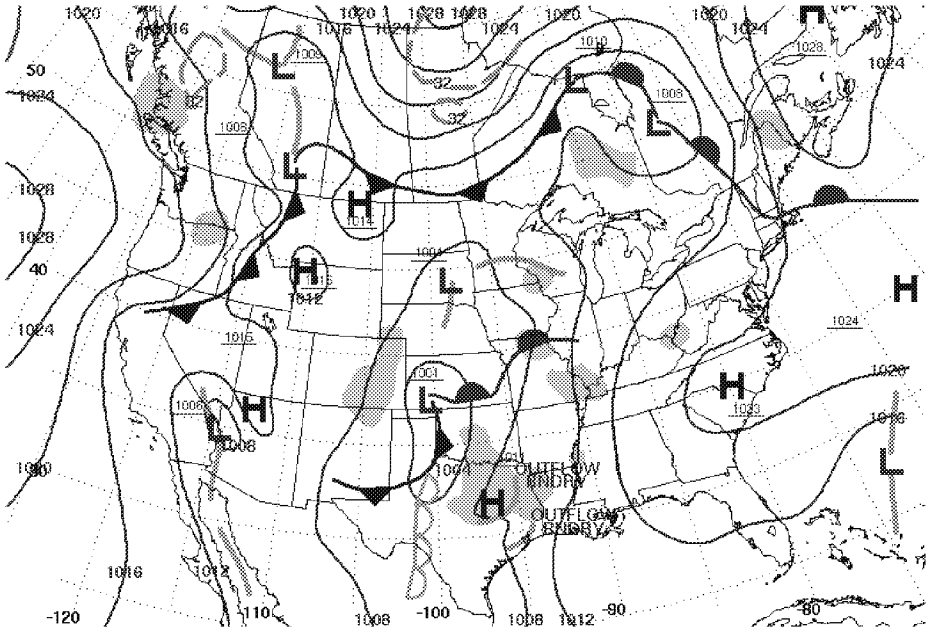
By May 25, the area of high pressure began to become better established across the Mid-Atlantic region. A stationary front to the north, which was draped from Wisconsin eastward toward northern Maine, acted as a barrier in air masses. The flow around the high centered over the Mid-Atlantic was from west to east across the northern Mid-Atlantic thanks to the presence of the stationary front across southeastern Canada.

Figure 18 – NOAA Surface Analysis on May 26, 2016 at 8 AM EDT



On May 26, the area of high pressure, which was over the eastern US on May 25, shifted east into a normal summertime position in the western Atlantic Ocean. Across the eastern US, a lee side trough (highlighted as an orange line on the map) was analyzed at 8 AM. The lee side trough acts as a focal point for wind (and pollution levels).

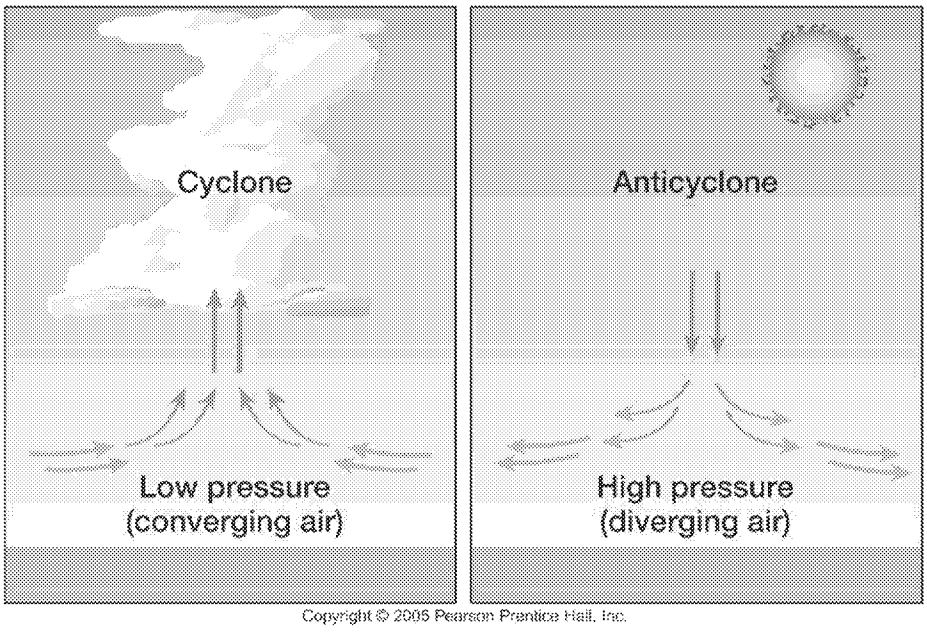
Figure 19 – NOAA Surface Analysis on May 27, 2016 at 8 AM



By May 27, the high pressure system across the western Atlantic Ocean was in full control of the weather across the eastern US. At the same time, a new storm system began to develop across the southern Plains. The flow along the western flank of the high was out of the south and then from west to east across the northern edge of the high (across Pennsylvania).

In this sequence of maps, the location of the area of high pressure is important. The flow around an area of high pressure is clockwise horizontally while the air sinks vertically. Figure 20 on the following page displays the vertical flow differences between a cyclone (an area of low pressure) and an anticyclone (an area of high pressure).

Figure 20 – Vertical Flow for Cyclones Versus Anticyclones



Source: Pearson Prentice Hall, Inc (copyright 2005)

To summarize the figure above, sinking air is associated with areas of high pressure. Therefore, the track of the high pressure system from the midwestern US on May 22 to the western Atlantic Ocean on May 26 triggered a vertical sinking air mechanism necessary to transport the smoke from aloft to near the surface just as the smoke traversed from the western Great Lakes eastward into the northeastern US.

During "normal" ozone episodes, maximum temperatures regularly climb well into the 80s if not into the 90s. On the first day (May 24) ozone levels began to rise across western PA, temperatures were in the upper 70s. Table 3 below illustrates the trend in high temperatures across the seven major Federal Aviation Administration (FAA) Automated Surface Observing Systems (ASOS) meteorological stations during the days in which the Department is requesting ozone concentrations be flagged for exceptional event purposes.

Table 3 – High Temperatures at Major FAA ASOS Stations Across Pennsylvania

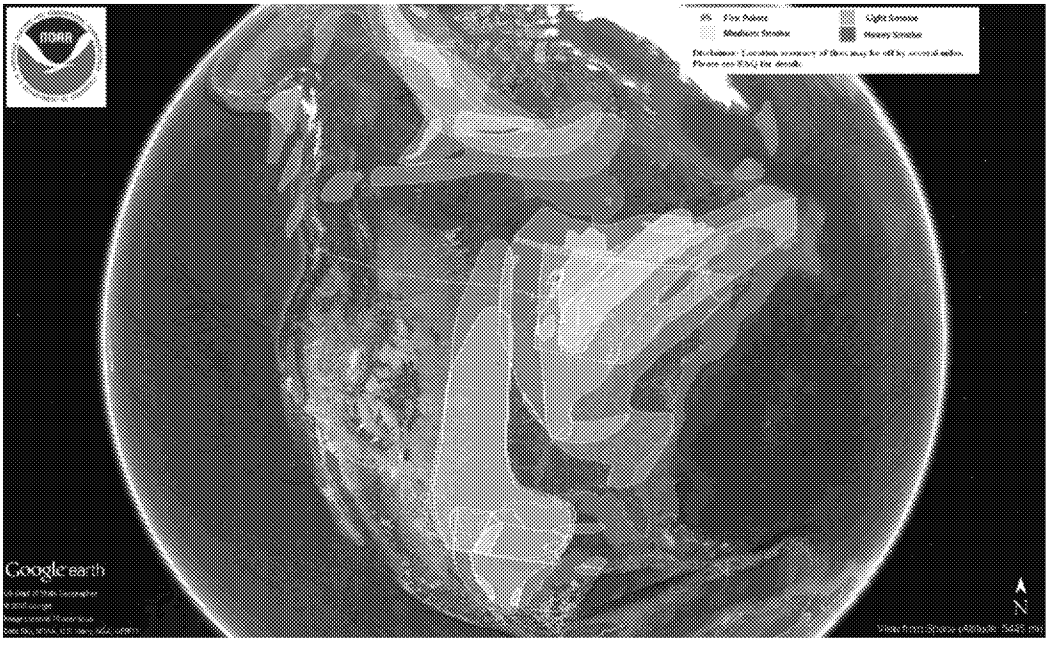
City	Airport	5/24/2016	5/25/2016	5/26/2016
Erie, PA	KERI	78	82	87
Pittsburgh, PA	KPIT	80	82	82
Altoona, PA	KAOO	77	84	83
Williamsport, PA	KIPT	85	89	86
Scranton, PA	KAVP	82	87	88
Harrisburg, PA	KMDT	86	85	86
Philadelphia, PA	KPHL	83	88	90

The overall meteorological pattern across the northeastern US was not favorable for ozone formation until the last day (May 26) of the episode in Pennsylvania. Therefore, on a meteorological basis, this event can be characterized as uncommon for ozone formation across the Commonwealth. Even with the favorable meteorological conditions (high pressure stationed across the western Atlantic and high temperatures approaching the 90 degree mark across Pennsylvania), the elevated precursor emissions (specifically VOC and NOx associated with the fire) were necessary for such a widespread ozone event to occur across Pennsylvania.

Fort McMurray Fire Meteorological Discussion – Satellite and Regional Ozone Analysis

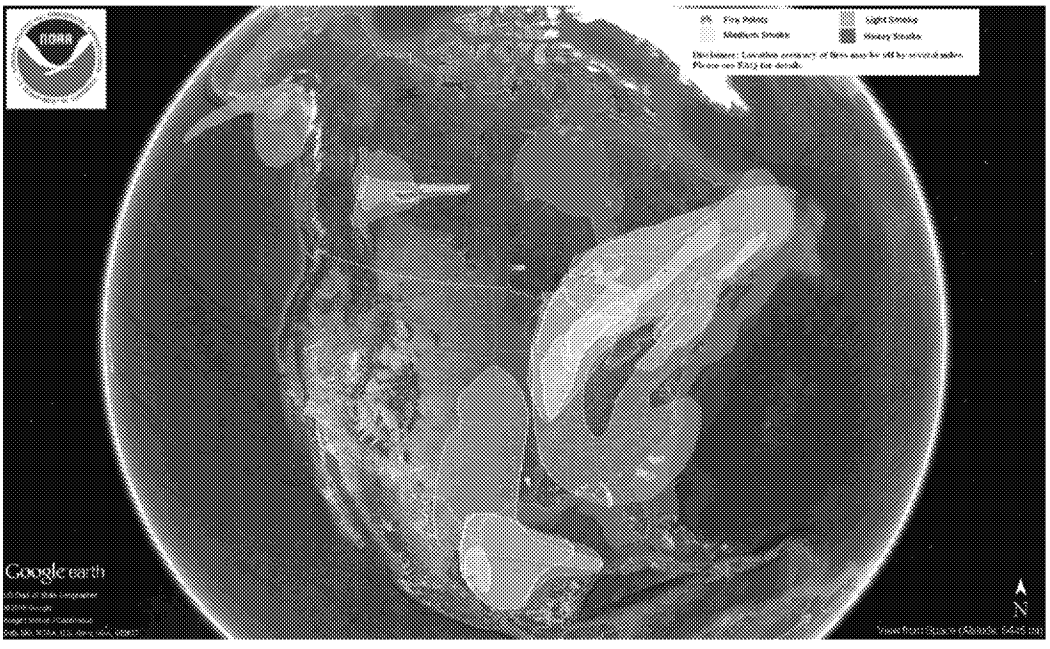
The satellite data, like the upper air and surface meteorology, illustrates that the smoke was able to transport eastward from the northern Plains to the northeastern US. Satellite imagery was analyzed from NOAA's HMS within Google Earth. Figures 21 to 25 illustrate the movement of the smoke during the May 23 to May 26 time frame.

Figure 21 – NOAA HMS Satellite Analysis for May 22



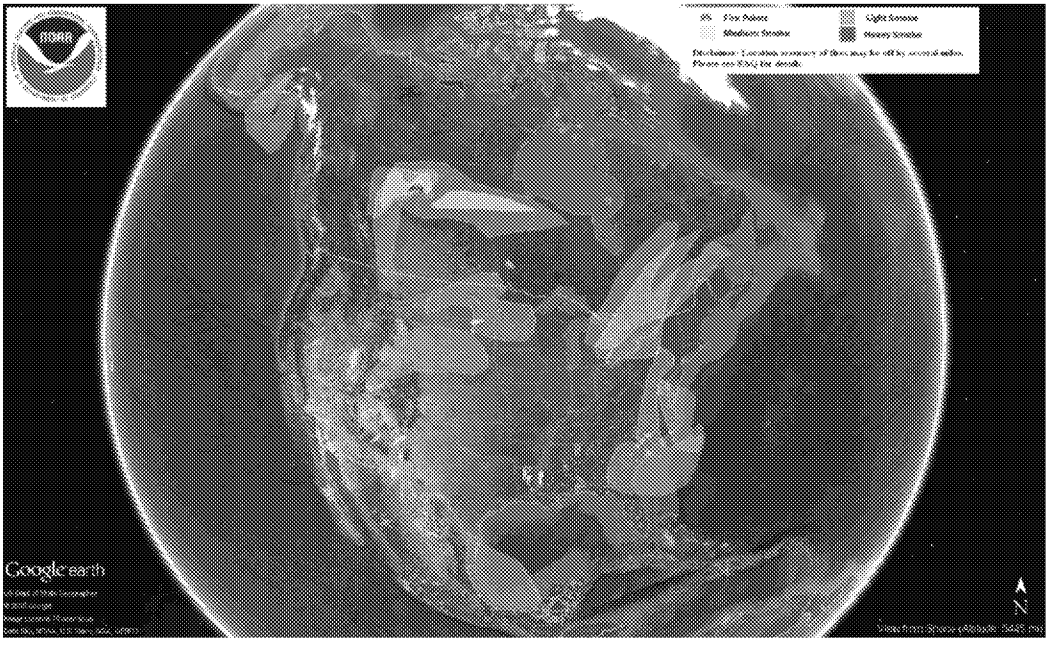
On May 22, medium smoke was analyzed entering into the western Great Lakes region. Lighter amounts of smoke were analyzed as far east as the eastern Great Lakes region.

Figure 22 – NOAA HMS Satellite Analysis for May 23



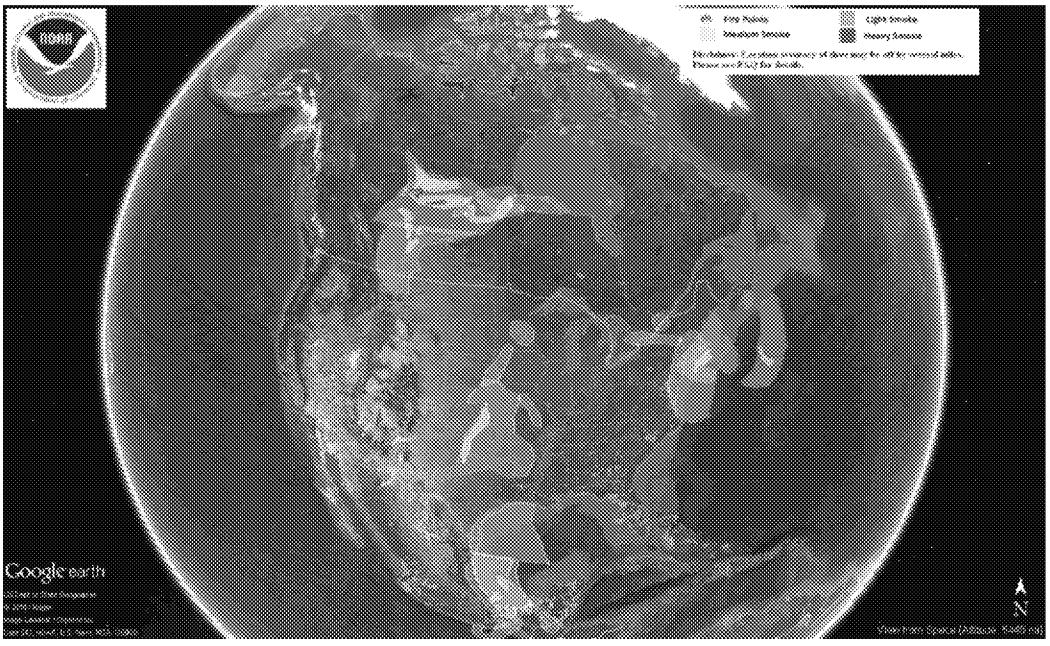
On May 23, the medium smoke, which was centered across the western Great Lakes on May 22, migrated eastward into the central Great Lakes region. Light smoke was reported moving east into portions of the eastern US.

Figure 23 – NOAA HMS Satellite Analysis for May 24



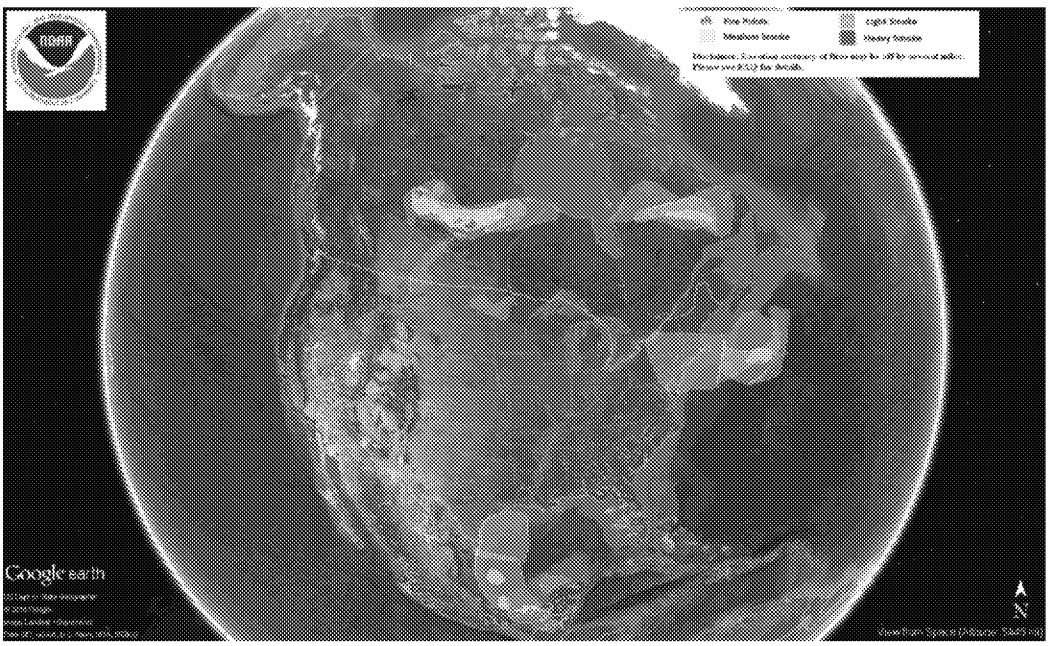
On May 24, only light amounts of smoke were analyzed across the northeastern US. The plume of smoke actually separated into two, with one centered across southeastern Canada and another centered across the southeastern US.

Figure 24 – NOAA HMS Satellite Analysis for May 25



On May 25, the plume that was centered across southeastern Canada on May 24, shifted east and off the New England coastline. Part of the smoke migrated south across eastern Pennsylvania and New Jersey.

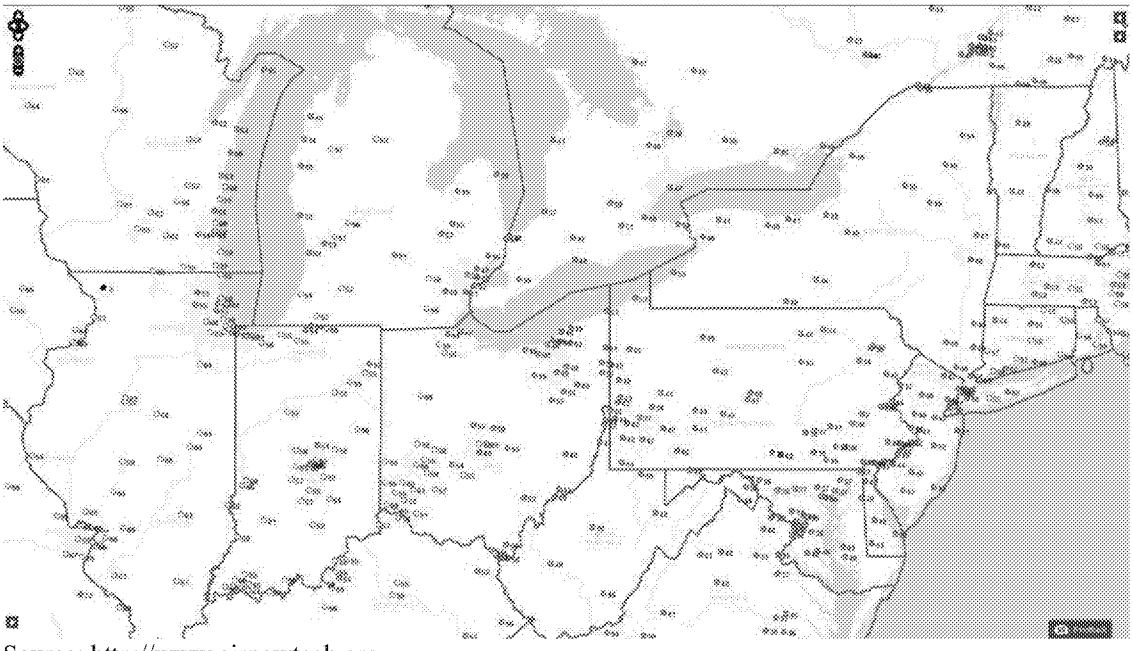
Figure 25 – NOAA HMS Satellite Analysis for May 26



By May 26, the heaviest smoke had moved out into the Atlantic Ocean. There continued to be light smoke reported across the northeastern US. Another plume of medium smoke was analyzed in the proximity of the Fort McMurray fires in Alberta, Canada.

Overall, the satellite analysis from May 22 to May 26 displayed the transport of smoke from west to east from the midwestern US through the northeastern US during the same time when ozone concentrations peaked across the same region. The eastward advection of smoke during this period correlated well with peak ozone concentrations during the period. Figures 26 to 30 displays the peak 8-hour ozone concentrations from May 22 to May 26.

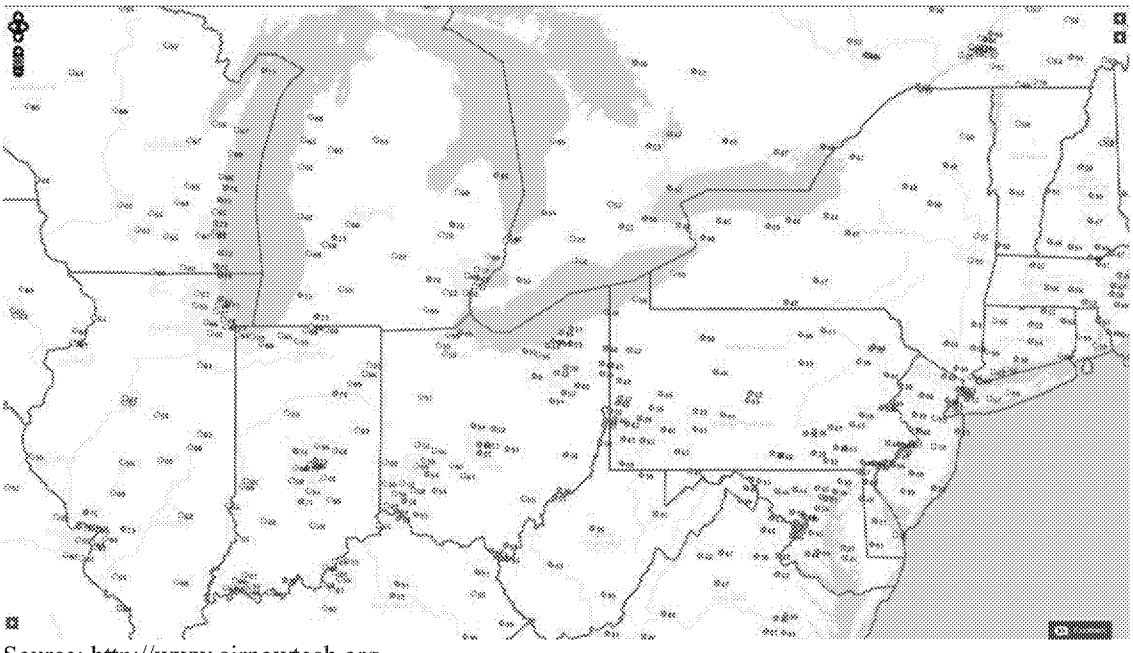
Figure 26 – 8-Hour Peak Ozone Concentrations from Sunday, May 22, 2016



Source: http://www.airnowtech.org

On May 22, ozone concentrations rose into the moderate range across Minnesota, Wisconsin, Iowa, Illinois, Indiana and Michigan. Low ozone concentrations persisted across many states in the northeastern US and Mid-Atlantic states. At this time, a weak frontal system was pushing through the northeastern US (creating the increase in clouds and rain across the region).

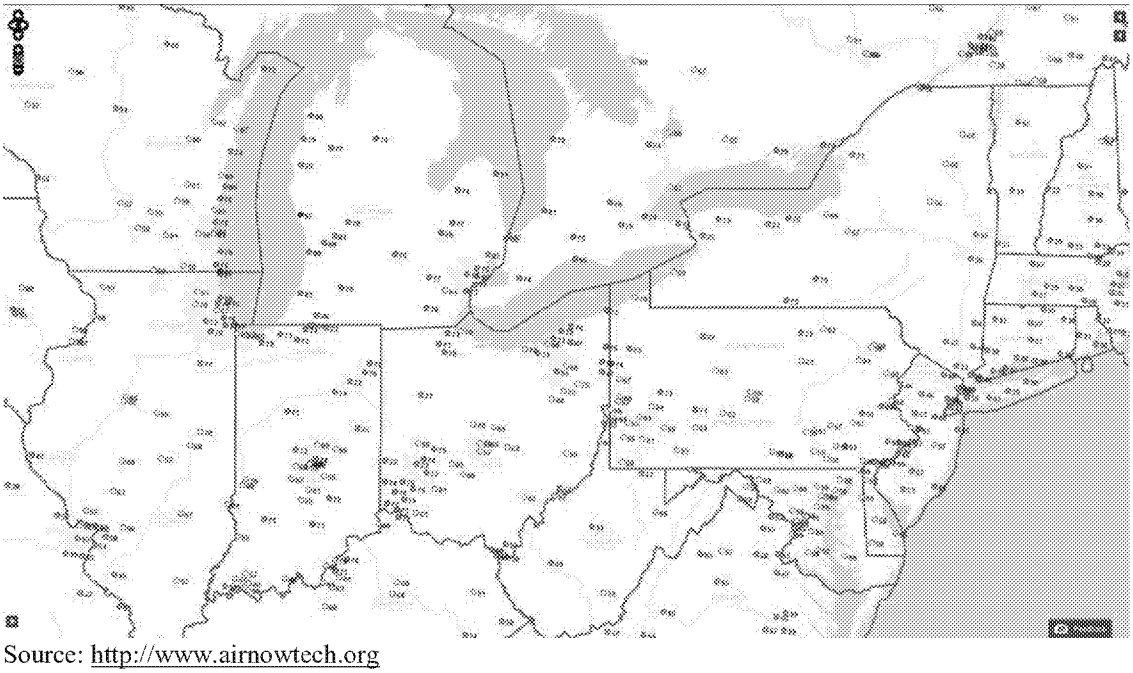
Figure 27 – 8-Hour Peak Ozone Concentrations from Monday, May 23, 2016



Source: http://www.airnowtech.org

On May 23, ozone exceedances began occurring along the western shore of the Lake Michigan along with areas around St. Louis, MO and spotty locations across Indiana and Michigan. During this same time, the heaviest smoke plume was over the central Great Lakes area along with an area of high pressure.

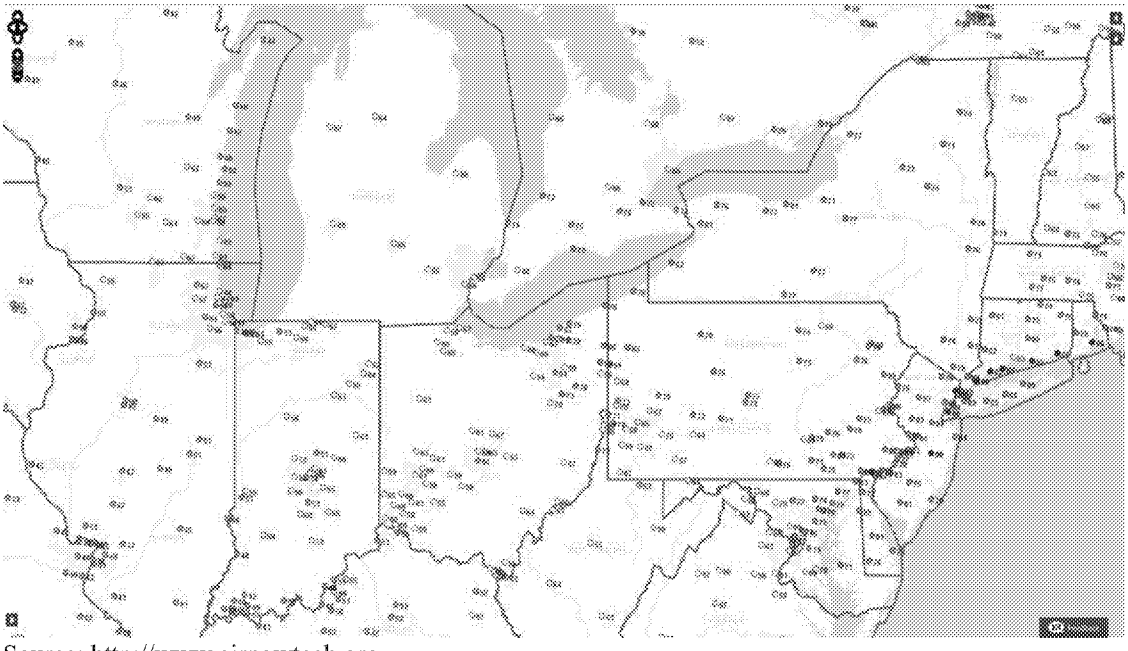
Figure 28 – 8-Hour Peak Ozone Concentrations from Tuesday, May 24, 2016



Source: http://www.airnowtech.org

On May 24, ozone exceedances became more widespread. The ozone exceedances on May 23, which were confined to the midwestern US and Great Lakes region, migrated eastward. Ozone exceedances were monitored in Indiana, Michigan, Kentucky, Ohio, western New York and northwestern Pennsylvania. These ozone exceedances coincided with the location of the heaviest smoke (across southeastern Canada / eastern Great Lakes region) and the location of the high pressure system across the eastern US.

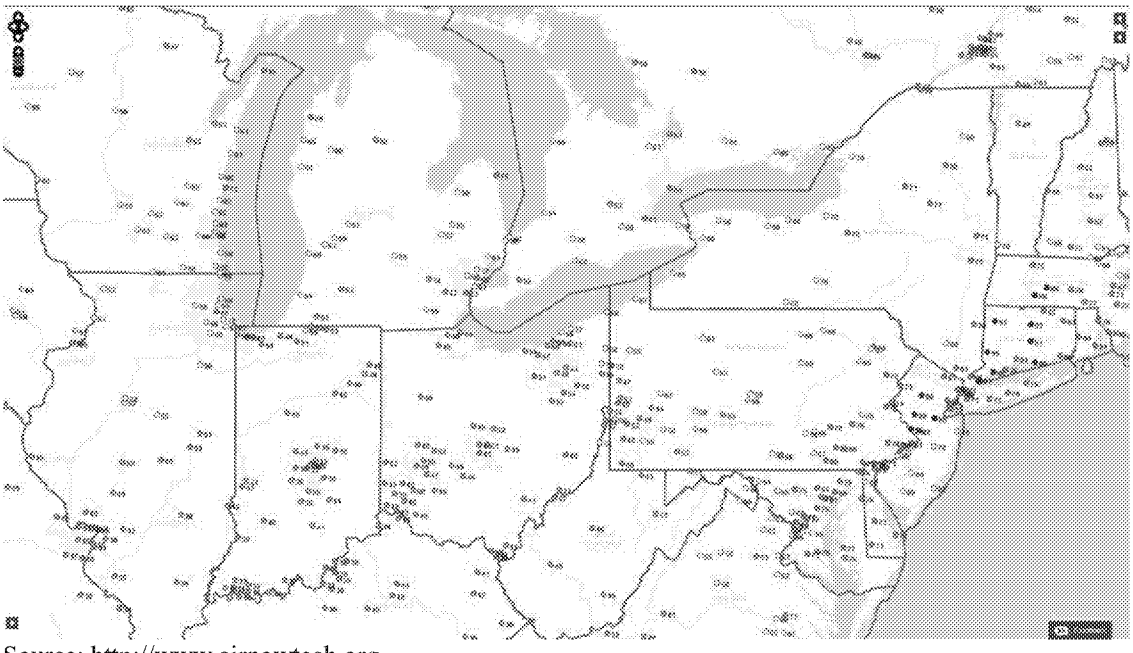
Figure 29 – 8-Hour Peak Ozone Concentrations from Wednesday, May 25, 2016



Source: http://www.airnowtech.org

By May 25, ozone exceedances continued their eastward progression through the northeastern US. Many locations across the Commonwealth and states to the south, east and north monitored ozone in exceedance of the 2015 ozone NAAQS. While the heaviest smoke plume was centered over eastern New England, the highest ozone concentrations were just to the west under the center of the high pressure system across the Mid-Atlantic.

Figure 30 – 8-Hour Peak Ozone Concentrations from Thursday, May 26, 2016



Source: http://www.airnowtech.org

On May 26, the peak ozone concentrations were along the I-95 corridor from northeast of Philadelphia to Connecticut. The surface weather analysis displayed the formation of a lee side trough, which is known to be a convergence zone for elevated ozone. The peak ozone concentrations also correlated with the remnants of smoke across the northeastern US.

Clear Causal Relationship Between the Fort McMurray Fires and Monitored Ozone Concentrations

The Department believes that the Fort McMurray fires contributed enough smoke across the northeastern US to impact ozone concentrations during the May 24 to May 26 period. The Department will present evidence that illustrates that smoke associated with the Fort McMurray fires clearly contributed to ozone formation beyond what is normally occurs in the absence of smoke and that the byproducts (VOC and NOx) in the smoke caused the ozone exceedance days. The Department completed an analysis of historical ozone concentrations over the last five years to determine how non-normal ozone concentrations were during the May 24 to May 26 period. In addition, a Tier 1 and Tier 2 Q/d analysis was developed to illustrate the smoke's impact across the Commonwealth.

Historical Monitoring Data Analysis

Within the Commonwealth, four federal/state/local agencies operate 53 ozone monitors. The Department currently operates 42 of the ozone monitors in 65 of the 67 counties. U.S. EPA currently operates five ozone monitors under the CASTNET program. Local agencies Allegheny County Health Department (ACHD) and Philadelphia Air Management Services (PAMS) each operate three ozone monitors.

Although, the Department monitors ozone year-round, the Department only analyzed ozone concentrations during the official ozone monitoring season (April 1 to October 31). In order to analyze these ozone concentrations, the Department developed scatter plots for all monitors outlined in Table 1 and Table 2. The Table 1 plots are below in Figures 31 to 33. The Table 2 plots are in Appendix A of this document. As part of the scatterplots, the Department analyzed the 99th percentile concentrations from two periods: all 2012 to 2016 ozone concentration data and just May 2012 to 2016 ozone concentration data. The Department is only requesting to flag the data for purposes of the exceptional event for any monitor's concentrations outlined in Table 1 and Table 2 that had an ozone concentrations during the May 24 to May 26 that was either the first, second, third or fourth high in 2016. The ranks of each of the peak 8-hour ozone concentrations are outlined in Table 1 and Table 2.

Figure 31 – Reading, PA Daily Ozone Season Maximums (2012-2016)

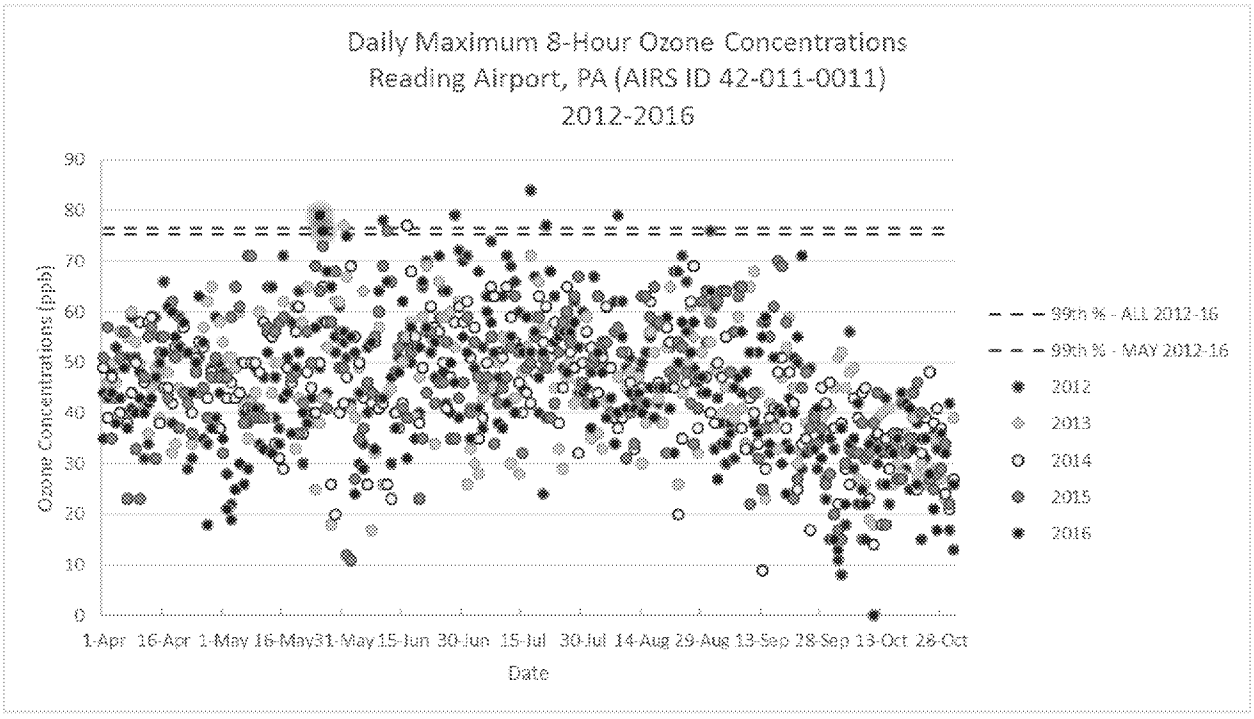


Figure 32– Lebanon, PA Daily Ozone Season Maximums (2012-2016)

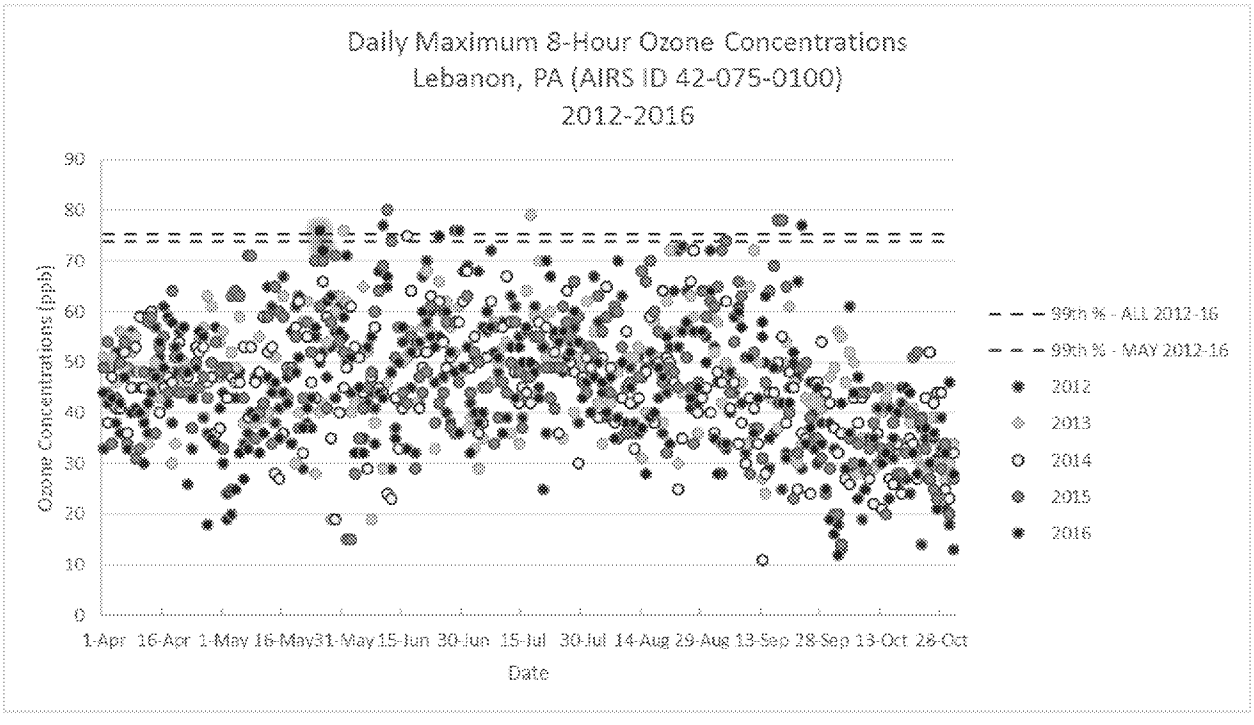
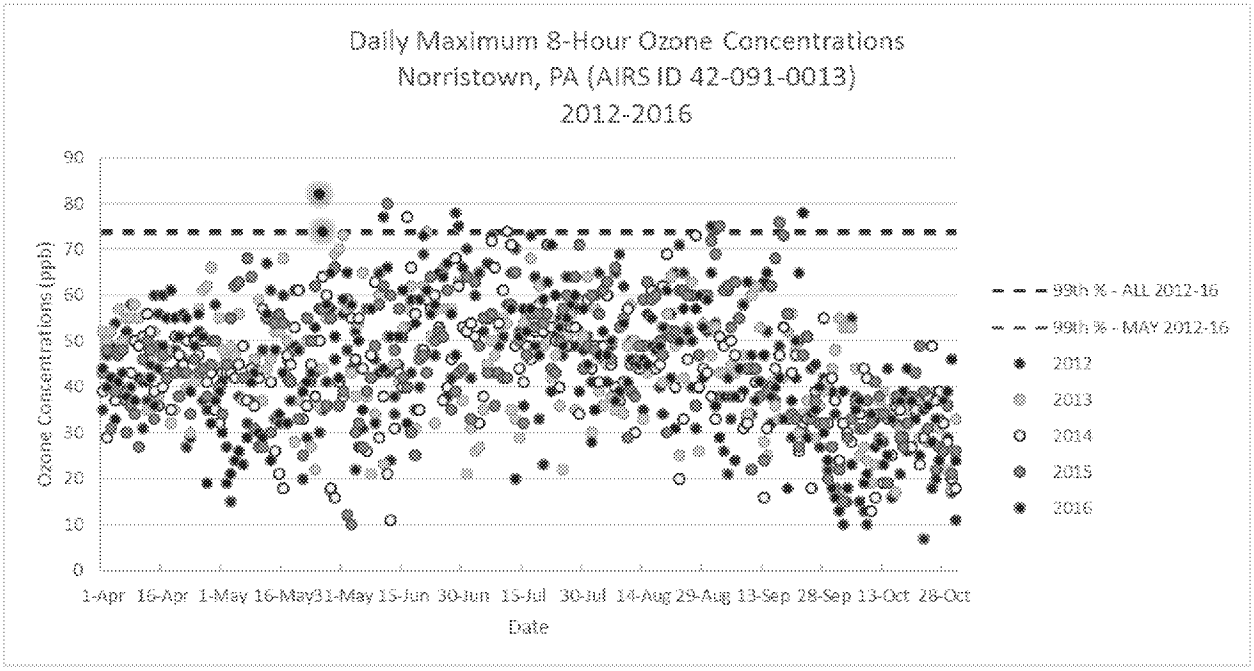


Figure 33 – Norristown, PA Daily Ozone Season Maximums (2012-2016)

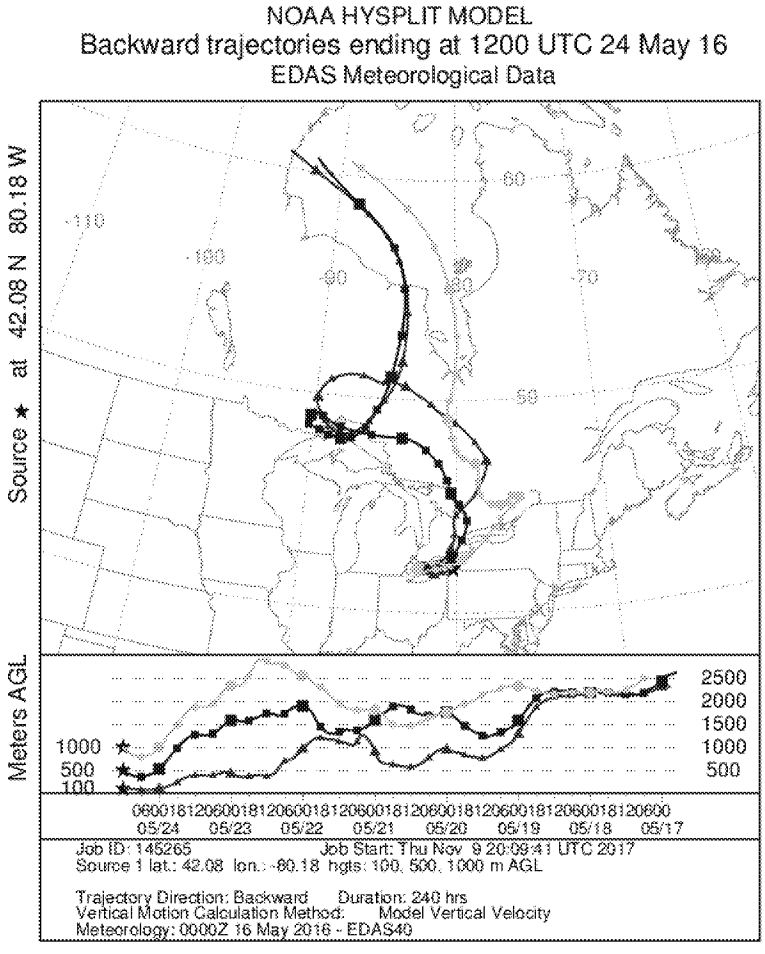


As illustrated in the red shaded areas in the three figures above, the May 25 and May 26 daily maximum 8-hour ozone concentrations were the highest 8-hour ozone concentrations monitored at Reading, Lebanon and Norristown during any May date from 2012 to 2016. In addition, each of the three monitors had at least one of the days' peak 8-hour ozone concentrations in excess of both the May 2012 to 2016's 99h percentile concentration and the entire ozone season 2012 to 2016's 99th percentile concentration. As a result, there must have been something exceptional contributing to the two exceedances on May 25 and May 26 of the 2015 ozone standard. The Department has seen similar ozone concentrations to those witnessed on May 25 and May 26 during the heart of summer, most recently in 2012. However, those exceedances were likely due to anthropogenic NOx emissions. When combined with the fact that the May 2016 CAMD emissions were the lowest of the last five years, the high concentrations during May 25 and May 26 were uncharacteristically high, suggesting the monitors were influence by smoke from the Fort McMurray fires.

Additional Evidence of Smoke Transport into Pennsylvania – Back Trajectories

To further examine the impact that the Fort McMurray fires had on ozone productions across Pennsylvania, the Department utilized the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to determine the progression of air parcels toward Pennsylvania in the May 24 to May 26 period. The general output from HYSPLIT displays two different plots: the top portion of the HYSPLIT output displays the horizontal geographic extent that the air parcel traveled and the bottom portion of the HYSPLIT output displays the vertical movement of the air parcel. The Department focused its analysis on the air mass within the boundary layer, which is why vertical levels of 100 meters, 500 meters, and 1000 meters were analyzed. Figures 34 to 36 are HYSPLIT backward trajectory analyses that were completed for the May 24 to May 26 time frame.

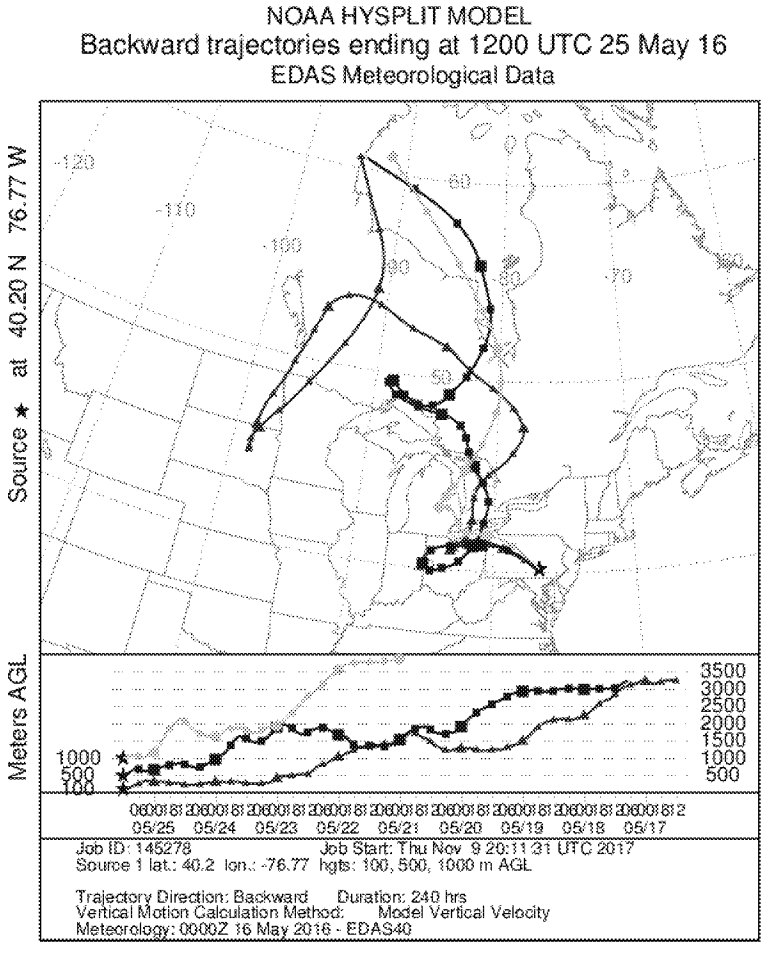
Figure 34 – HYSPLIT Back Trajectory for Erie, PA – May 24, 2016



On May 24, the Department analyzed the backward trajectory at Erie, PA because the highest ozone concentrations in Pennsylvania were concentrated in the northwestern portion of the Commonwealth. The backward trajectory displayed the air parcel's trip from the Hudson Bay region of Canada southward across the Great Lakes and into Erie, PA during the time in which

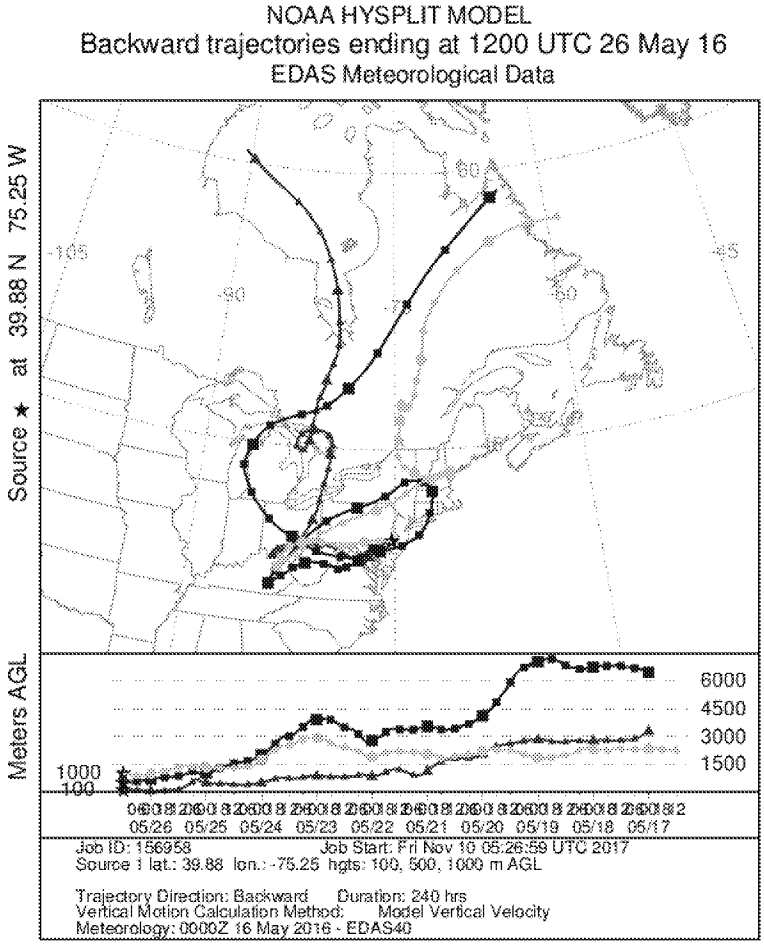
the smoke plume was centered across the Great Lakes region. The vertical profile of the trajectory illustrates that air parcels from approximately 2500 meters in height descended to the 100-meter to 1000-meter height level at Erie over the course of the trajectory. This is indicative of a sinking air motion across northwestern Pennsylvania on May 24.

Figure 35 – HYSPLIT Back Trajectory for Harrisburg, PA – May 25, 2016



On May 25, the Department analyzed the backward trajectory at Harrisburg, PA because the highest ozone concentrations in Pennsylvania were concentrated across the central portion of the Commonwealth. The backward trajectory displayed the air parcel's trip from the Hudson Bay region of Canada southward across the Great Lakes and into Harrisburg, PA during the time in which the smoke plume was moving east across the northeastern US. The vertical profile of the trajectory illustrates that air parcels from approximately 3500 meters in height descended to the 100-meter to 1000-meter height level at Harrisburg during the duration of the trajectory. This is indicative of a sinking air motion across central Pennsylvania on May 25.

Figure 36 – HYSPLIT Back Trajectory for Philadelphia, PA – May 26, 2016



On May 26, the Department analyzed the backward trajectory at Philadelphia, PA because the highest ozone concentrations in Pennsylvania were concentrated across the eastern portion of the Commonwealth. The backward trajectory displayed the air parcel's trip from eastern Canada southward across the Great Lakes and the northeastern US states on its way into Philadelphia, PA during the time in which the smoke plume was still aloft over the northeastern US. The vertical profile of the trajectory illustrates that air parcels from approximately 6000 meters in height descended to the 500-meter height level over Philadelphia during the duration of the trajectory. This is indicative of a sinking air motion across eastern Pennsylvania on May 26.

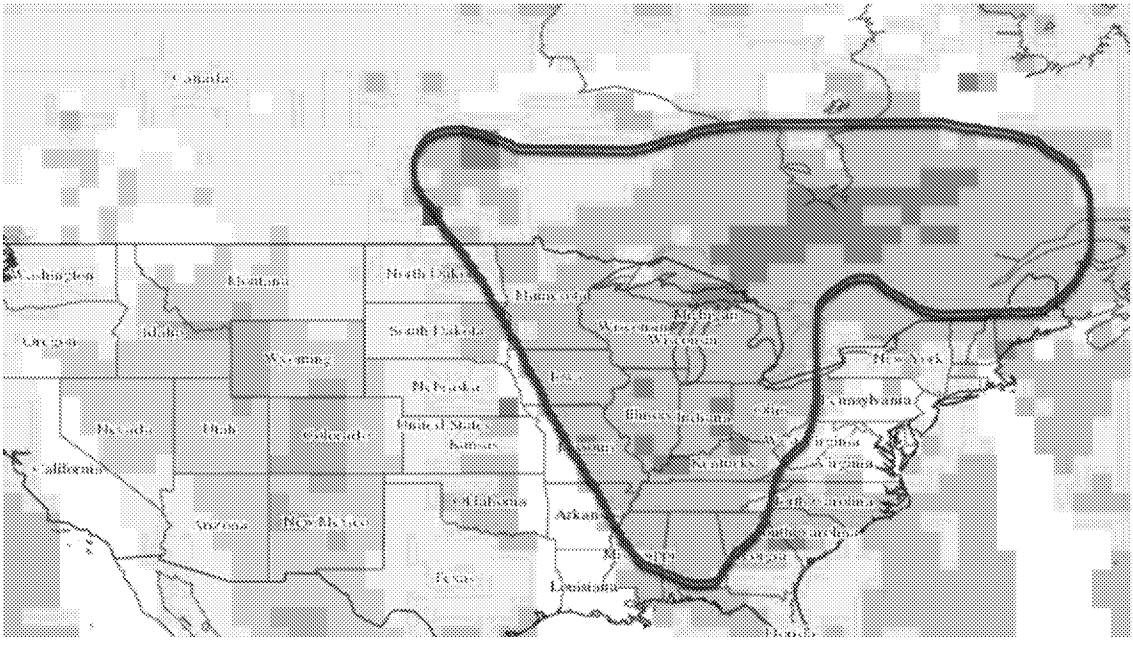
On all three days, the air parcel's movement from heights ranging from approximately 3000 to 6000 meters down toward the boundary layer (from 100 meters to 1000 meters) is indicative of the smoke aloft being mixed down the surface. As illustrated in the Fort McMurray Fire Meteorological Discussion sections above, the sinking motion was likely due to the presence of surface high pressure over the region. On May 24, the surface high was centered along the Appalachian Mountains, which likely influenced the air mass impacting Erie, PA. By May 25, the center of the area of high pressure moved slightly east across the Mid-Atlantic, thus allowing the highest concentrations to shift east across the Commonwealth. On May 26, the high pressure system shifted even further east over the western Atlantic Ocean. Remnant smoke across the

northeastern US coupled with more favorable wind flow across the northeastern US contributed to continued growth of ozone concentrations.

Additional Evidence of Smoke Transport into Pennsylvania – Satellite Data

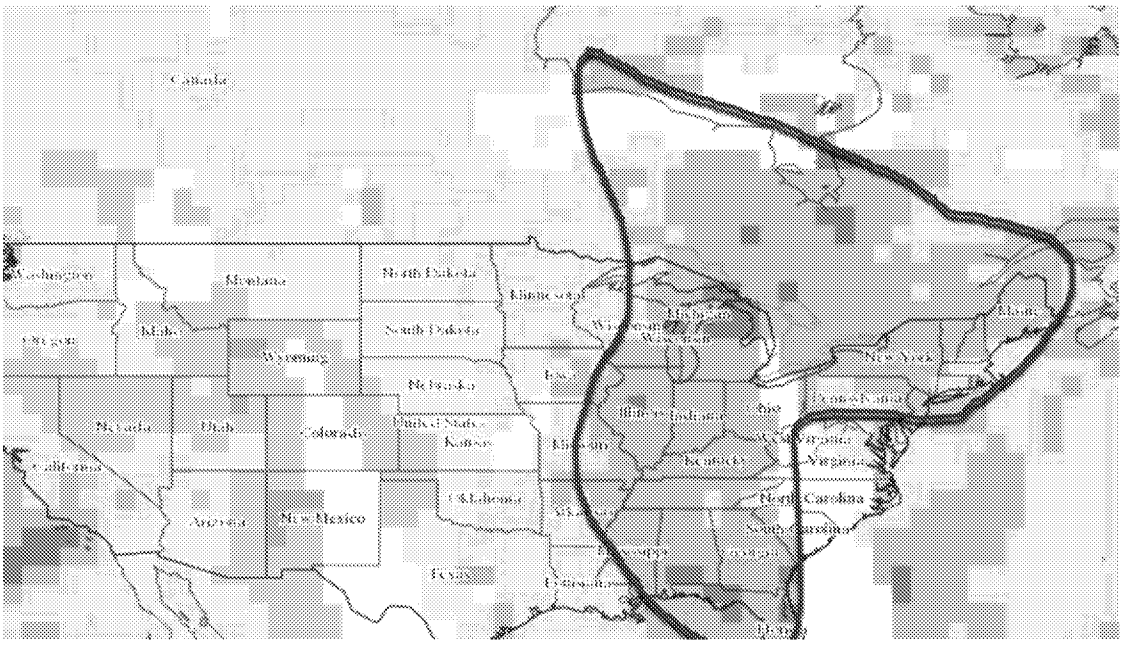
In a previous section entitled Fort McMurray Fire Meteorological Discussion – Satellite and Regional Ozone Analysis, the Department discussed NOAA HMS's satellite analysis illustrating the transport of smoke across the Great Lakes and northeastern US. Satellites can also track the presence of emissions in the atmosphere. As early as 2001 (in a study by M.O. Andreae and P. Merlet), carbon monoxide (CO) emissions have been identified as a wildfire smoke tracer, which can play a role in ozone production. Satellites actually measure total column CO, which is a summation of the CO in the column of air between the upper portion of the atmosphere and the surface. Overall, the CO's track during the May 22 to May 26 time frame coincided with the movement of smoke across the Great Lakes and northeastern US. Figures 37 to 41 illustrate the satellite's interpretation of the CO plume from the NASA Giovanni program (all satellite analyses were extracted from the NASA Giovanni website: https://giovanni.gsfc.nasa.gov/giovanni/).

Figure 37 – NASA Carbon Monoxide Satellite Analysis – May 22, 2016



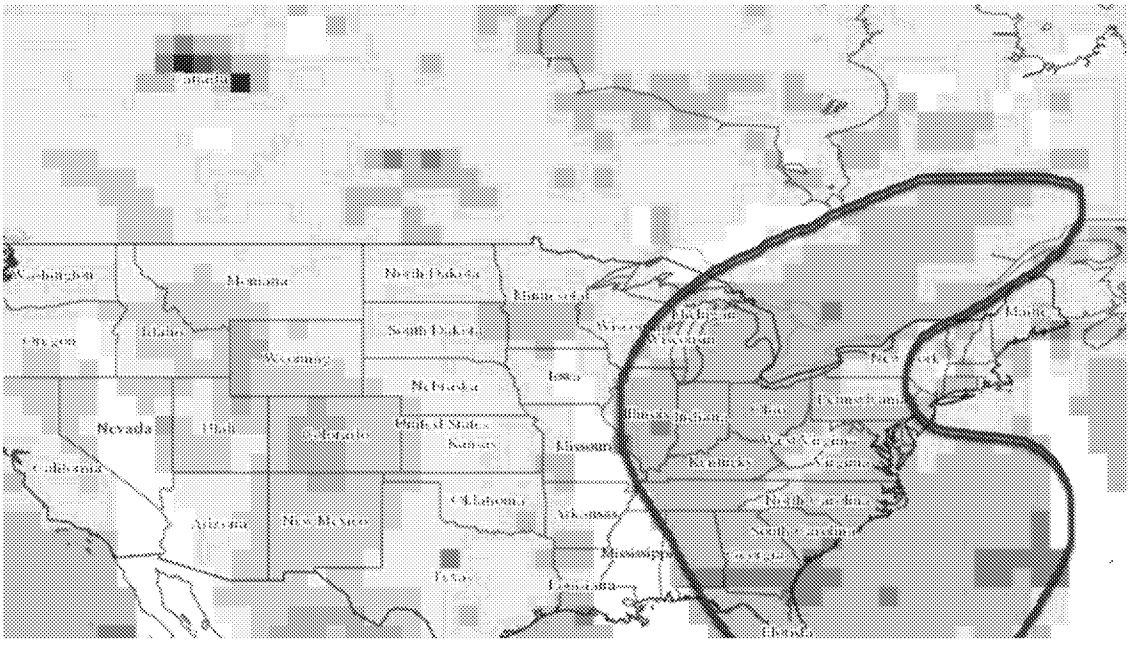
On May 22, the CO plume (with peak concentrations highlighted with the black outline) shifted to a position across southeastern Canada and southward across the midwestern US and the Ohio Valley region.

Figure 38 – NASA Carbon Monoxide Satellite Analysis – May 23, 2016



On May 23, the CO plume shifted further east. The highest concentrations were still centered over the Great Lakes but the axis of elevated impacts extended across the southeastern and northeastern US. In fact, the elevated CO had made its way far enough east to be over Pennsylvania.

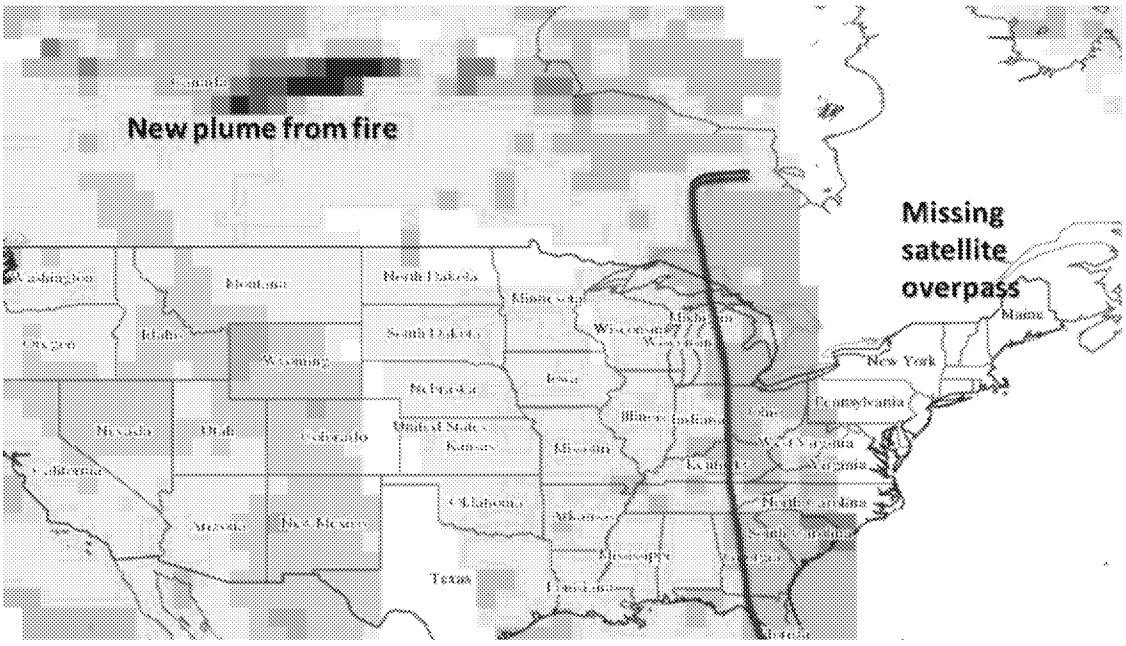
Figure 39 – NASA Carbon Monoxide Satellite Analysis – May 24, 2016



On May 24, the elevated CO slid even further east. At this time, the plume, which was centered across the eastern Ohio Valley region, extended its influence northeast into southeastern Canada

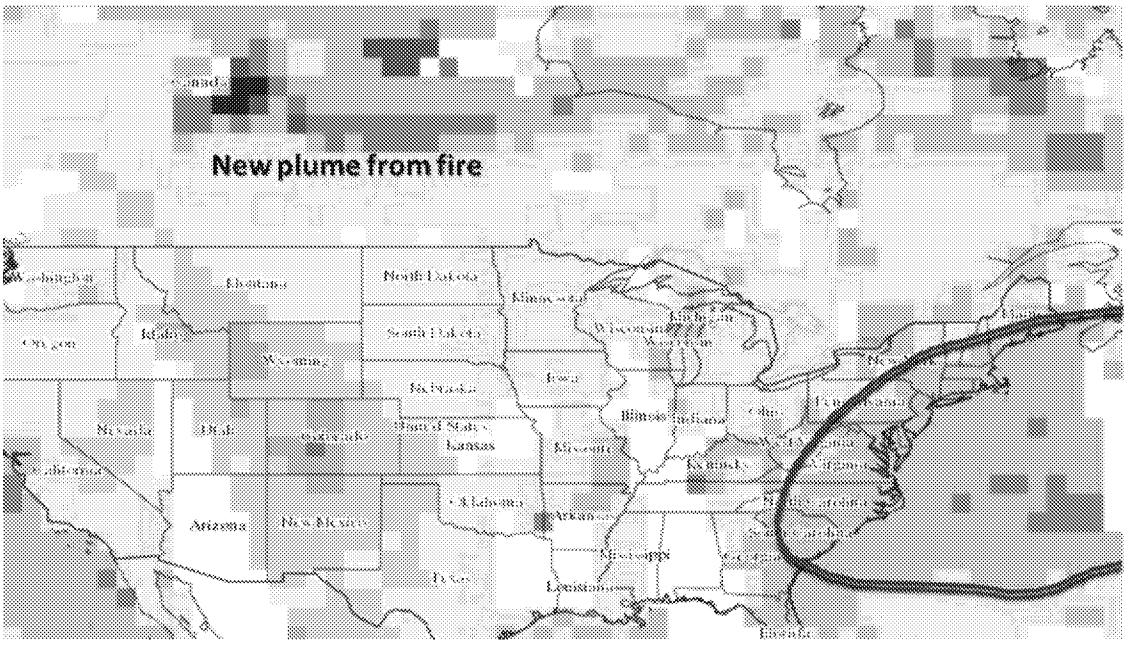
and southeast into the southeastern US. At the same time, elevated CO levels were illustrated by the satellite near the Fort McMurray fire location in western Canada.

Figure 40 – NASA Carbon Monoxide Satellite Analysis – May 25, 2016



On May 25, elevated CO continued to be reported across the eastern US. Due to a missing satellite overpass, the exact extent of the CO plume across the northeastern US into the western Atlantic Ocean was unknown so conclusions toward the impact across the East Coast could not be made on this day. However, elevated CO continued to be produced downwind of the Fort McMurray fire location in Alberta, Canada.

Figure 41 – NASA Carbon Monoxide Satellite Analysis – May 26, 2016



Finally, on May 26, the elevated CO plume, which had progressed east over the previous four days, had continued its eastward movement and shifted out into the Atlantic Ocean. This occurred just as the new CO plume surrounding the Fort McMurray fires extended its geographical extent east across southcentral Canada.

Overall, the analysis of the total column CO presented in the previous five figures illustrates not only that the highest CO levels corresponded to the location of the smoke presented in the NOAA HMS analysis in a previous section of this demonstration but that emissions associated from the Fort McMurray fires were transported over Pennsylvania from May 24 to May 26.

Analysis of the Fort McMurray Fire Emissions by Distance (Q/d)

As part of the publication of U.S. EPA's Exceptional Event Rule in the Federal Register, U.S. EPA released a guidance memo entitled *Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations*. As part of the guidance document, U.S. EPA recommends completing an analysis comparing the ratio of emissions from the wildfire (Fort McMurray in this case) over the transport distance (Q/d) as a rough assessment of the ability of a wildfire to cause increased ozone concentrations. The Q/d analysis is simply a comparison of the ratio of Q, the daily tons of VOC and NOx emitted from the fire, to d, the distance in kilometers from the fire to the point of concern, in this case Pennsylvania. If the Q/d value compares favorably to analytical data from other fires, then the fire can be presumed to have had a causal effect on ozone concentrations at the point of concern.

Based on a dataset which included four fires from 2011, U.S. EPA developed its guidance to demonstrate that a fire should have a Q/d in excess of 100 tons per day per kilometer (tpd/km) in order to be considered to have a clear causal impact on ozone. This method is intended to be a simple and conservative approach to establishing clear causality. Failure to meet the 100 ton per day per kilometer threshold does not preclude a finding clear causality.

Estimation of Q

The emissions from the fire can be estimated using information from U.S. EPA's AP-42 Compilation of Air Emission Factors Section 13.1 Wildfires and Prescribed Burning. The equations given are as follows:

Fi = Pi * L (Equation 1)
Ei = Fi * A (Equation 2)

Fi = emission factor (mass of pollutant/unit area of forest consumed)
Pi = yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)
= 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH4)
= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NOx)
L = fuel loading consumed (mass of forest fuel/unit land area burned)
A = land area burned
Ei = total emissions of pollutant "i" (mass pollutant)

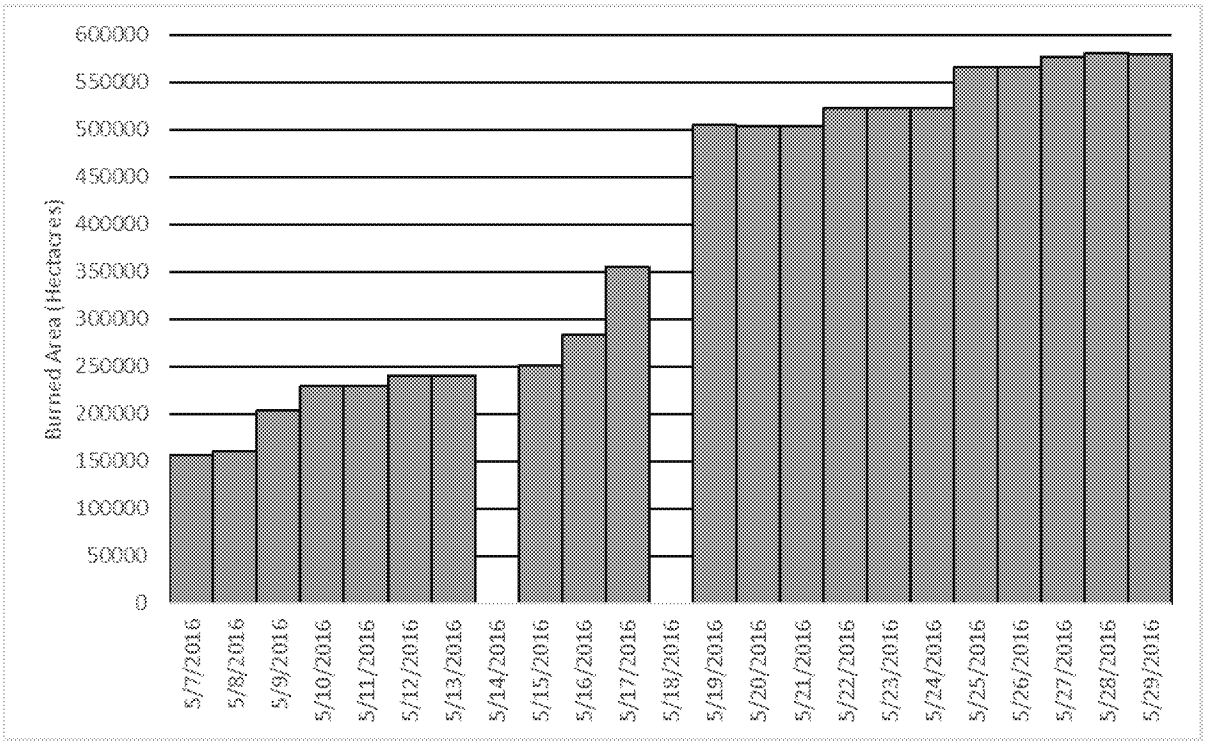
Combining equations 1 and 2, we have:

Ei = Pi * L * A

Pi is given above for total hydrocarbons and for nitrogen oxides. The fuel loading is given in AP-42 for different regions of the United States and ranges from 9 to 60 tons per acre. Conservatively, we will estimate a low-end emission rate using 10 tons per acre which is associated with northcentral US conifer forests. Note that our results could increase by a factor of 6 were we to expect the high end of emissions.

The Alberta government reported that by June 10, 2016 the fire ultimately covered 589,995 hectares (1,457,909 acres) with a perimeter of 996 kilometers (618 miles). For reference, the total land area of Rhode Island is approximately 270,000 hectares. Figure 42 displays the number of hectares that were burned as a result of the Fort McMurray wildfire. The hectares were reported by the Alberta government and were updated at least once a day. Data was not reported on May 14 and May 18, which is why the graph below is blank for those two days. Between May 17 and May 19, the fire size increased by over 150,000 hectares, which ultimately led to the increase in emissions during that time frame.

Figure 42 – Burned Area Reported by Alberta Government to be Covered by the Fort McMurray Fires in May 2016



Source: https://www.alberta.ca/release.cfm?xID=41701e7ECBE35-AD48-5793-1642c499FF0DE4CF

In the week (May 15 to May 22) leading up to the exceptional event in Pennsylvania, the fire grew by approximately 271,892 hectares (671,860 acres). Therefore, ignoring the smoldering of previously burned areas, we estimate the total hydrocarbon emissions from the week to be:

Ehc = 24 lbs of HC / ton of forest fuel consumed * 10 tons fuel / acre * 671,860 acres
Ehc = 161,246,400 pounds of HC
Ehc = 80,623 tons of HC emitted during the period from May 15 to May 22

Similarly for NOx:

Enox = 4 lbs of NOx / ton of forest fuel consumed * 10 tons fuel / acre * 671,860 acres
Enox = 26,874,400 pounds of NOx
Enox = 13,437 tons of NOx emitted during the period from May 15 to May 22

Q is the total daily emission rate in tons per day of reactive hydrocarbons and nitrogen oxides. U.S. EPA recommends in the exceptional events guidance that only 60% of the hydrocarbons should be considered reactive. Therefore, the reactive hydrocarbon emissions become rHC = 0.6 * Ehc or 0.6 * 80,623 = 48,374 tons of reactive HC emitted during the period of interest. Unlike for reactive hydrocarbons, no adjustments are suggested for the NOx emissions. Therefore, the total rHC and NOx emissions over the period are 48,374 + 13,437, or 61,811 tons over the six days. On average this results in a daily emission rate, or Q, of 10,301 tons per day (tpd). However, data from Alberta shows that most of these emissions came over a period of four days, (May 15 to May 19). A more reasonable estimate is 61,811/4 = 15,453 tpd.

Estimation of d

Based on the large distance, there will not be individual analyses completed for each monitor in Pennsylvania. However, an estimate of the distance from the Fort McMurray fire to the most distant monitor in Pennsylvania will be calculated. This estimate will supply a conservative, yet representative, distance the smoke traveled to Pennsylvania to impact its ozone monitoring network. As a result, a value of 3,190 km was therefore used for d, the "as the crow flies" distance from Fort McMurray to the Department's Bristol monitor, which is located to the northeast of Philadelphia, PA.

Q/d Estimate

Using the values determined above, Q/d becomes 15,453 tpd divided by 3,190 km or 4.84 tpd/km. This value is well below the U.S. EPA recommended level of 100 tpd/km indicating clear causality. Taking a less conservative approach and recalling that a worst-case fuel loading would increase our results by a factor of six, the Q/d calculation would be 29 tpd/km, which still would not meet U.S. EPA's recommended level of 100 tpd/km indicating clear causality. While this approach might be justified by the ongoing smoldering of the peat, the intensity of the Fort McMurray fire, variability in the burn rate, and other factors, it is difficult to justify without further details that may only be obtained through estimates which introduce their own error.

Taking a slightly different approach, the Department considered the basis for the U.S. EPA guidance and looked at emissions from one of the four fires U.S. EPA relied on in developing their guidance. Appendix A2 of the U.S. EPA guidance indicates that U.S. EPA based their conclusions on 12 km grid CMAQ modeling of four 2011 multiday fires: Wallow, Waterhole, Big Hill and Flint Hills. Emissions from the fires were based on a program called SMARTFIRE. Using information available on the Wallow Fire, we can approximate the emissions that might be calculated for the Fort McMurray fire.

The Wallow Fire burned in eastern Arizona and western New Mexico from May 29, 2011 through July 8, 2011 and burned 841 square miles (538,240 acres) by June 26, 2011. Based on presentations given by Kirk Baker, U.S. EPA, in 2015, the maximum daily emissions from that fire were reported as approximately 15,000 tons of rVOC and 1,000 tons of NOx. If we scale this fire up by a factor of three to approximate the acreage burned in the Fort McMurray fire, then we have daily emissions as high as 45,000 tons for rVOC and 3,000 tons for NOx. These

emissions produce a Q of 48,000 tpd and Q/d becomes 15.0, which is still well below U.S. EPA's expectation for causality.

Noting the wide variability in emissions estimates from different approaches, and as the Q/d method does not generally satisfy the expectation of a clear causal impact, we present other evidence demonstrating that the plume from the Fort McMurray fire caused elevated ozone levels in Pennsylvania.

Evidence that the Fort McMurray Fire Emissions Affected Monitors Across the Great Lakes and Pennsylvania

In addition to analyzing the Fort McMurray fires' impact on ozone concentrations across the Commonwealth, the Department analyzed fine particulate ($PM_{2.5}$) and $PM_{2.5}$ speciation concentrations. The Department has completed an analysis of the $PM_{2.5}$ data in Pennsylvania from May 21 to May 27. On May 24 and May 25, $PM_{2.5}$ concentrations rose from west to east across the Commonwealth. This rise in $PM_{2.5}$ concentrations coupled with elevated organic carbon and potassium ion data found on the $PM_{2.5}$ speciation filters during the same time frame clearly illustrates the air across Pennsylvania was impacted by wildfire smoke.

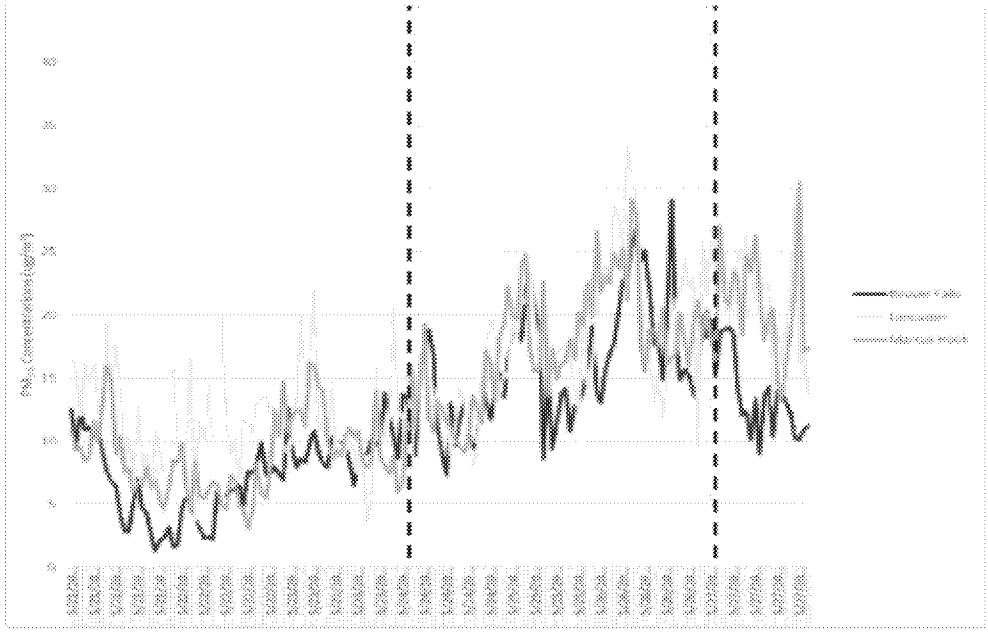
$PM_{2.5}$ in Pennsylvania

The Department operates thirty-two continuous $PM_{2.5}$ monitors across the Commonwealth. As part of its analysis, the Department analyzed hourly $PM_{2.5}$ concentrations from three of its continuous $PM_{2.5}$ monitors:

1.) Beaver Falls in western PA (AQS ID 42-007-0014)
2.) Lancaster in southcentral PA (AQS ID 42-071-0007)
3.) Marcus Hook in southeastern PA (AQS ID 42-045-0109)

Figure 43 illustrates the trend in hourly $PM_{2.5}$ concentrations at the three monitors listed above from May 21 to May 27. The first blue dashed line marks the beginning of May 24 and the second blue dashed line marks the beginning of May 27.

Figure 43 – Trend in Pennsylvania Hourly $PM_{2.5}$ Concentrations – May 21 to May 27



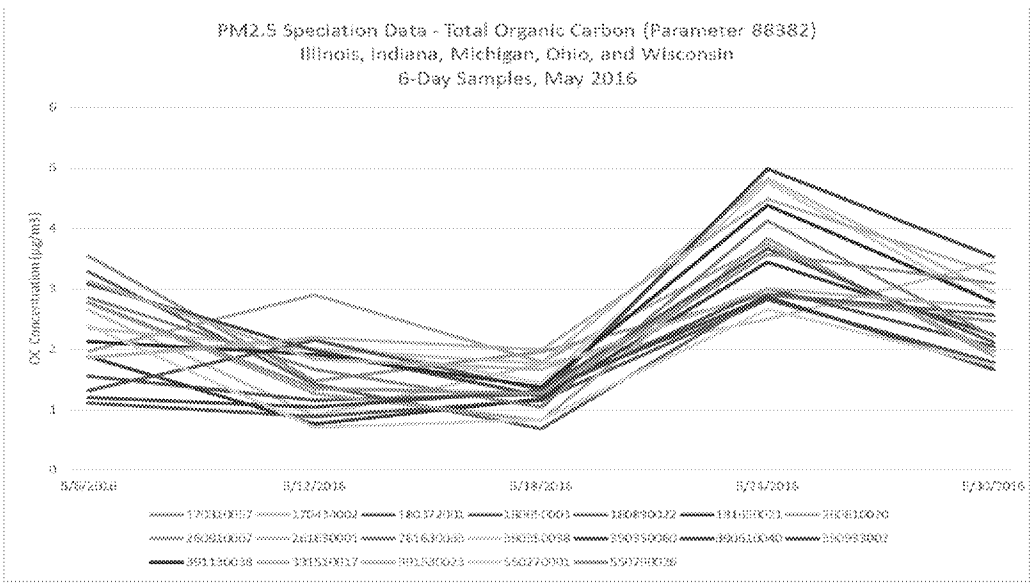
As illustrated in the graph, $PM_{2.5}$ concentrations began the period on the low side, with Beaver Falls and Marcus Hook primarily reading in the single digits. By May 24, $PM_{2.5}$ concentrations began to increase. On May 25, hourly $PM_{2.5}$ concentrations were registering in the 20 ug/m^3 range. On May 26, hourly $PM_{2.5}$ concentrations reached in the mid to upper 20 ug/m^3 range. The timing of the rise in hourly $PM_{2.5}$ concentrations coincided with the track of the smoke laden air mass as it traveled across the Commonwealth.

Speciated $PM_{2.5}$ Across the Great Lakes and Ohio Valley States

Various states across the US operate $PM_{2.5}$ speciation monitors to assess what constituents of $PM_{2.5}$ contribute to $PM_{2.5}$ formation on any given day. Most $PM_{2.5}$ speciation monitors operate on a 1-in-6 day schedule. In May 2016, there were five days in which $PM_{2.5}$ monitors ran: May 6, May 12, May 18, May 24, and May 30. Since much of the impact with regards to high ozone concentrations across Pennsylvania occurred on May 24 to May 26, the Department analyzed $PM_{2.5}$ speciation data from monitors operating on May 24. The Department's May 24 geographical focus was in the five states centered in the Great Lakes and Ohio Valley, including Illinois, Indiana, Michigan, Ohio and Wisconsin. As illustrated in the Conceptual Model for Ozone Formation during the Fort McMurray fires section above, the smoke laden air mass was positioned across the Great Lakes and Ohio Valley on May 24. Therefore, analyzing the May 24 $PM_{2.5}$ speciation data over the Great Lakes and Ohio Valley proved vital to determining if the air mass moving in over the Commonwealth had previously witnessed impacts from the forest fires.

With respect to the $PM_{2.5}$ speciation data in the five states listed above, the Department analyzed organic carbon and the potassium ion. Wildfires produce VOCs and NOx and the Fort McMurray fire was no different. Therefore, elevated levels of organic carbon and the potassium ion are good indicators of whether an air mass filled with smoke is reaching the ground. Figure 44 displays the trend of organic carbon at various $PM_{2.5}$ speciation monitors across the five states listed above.

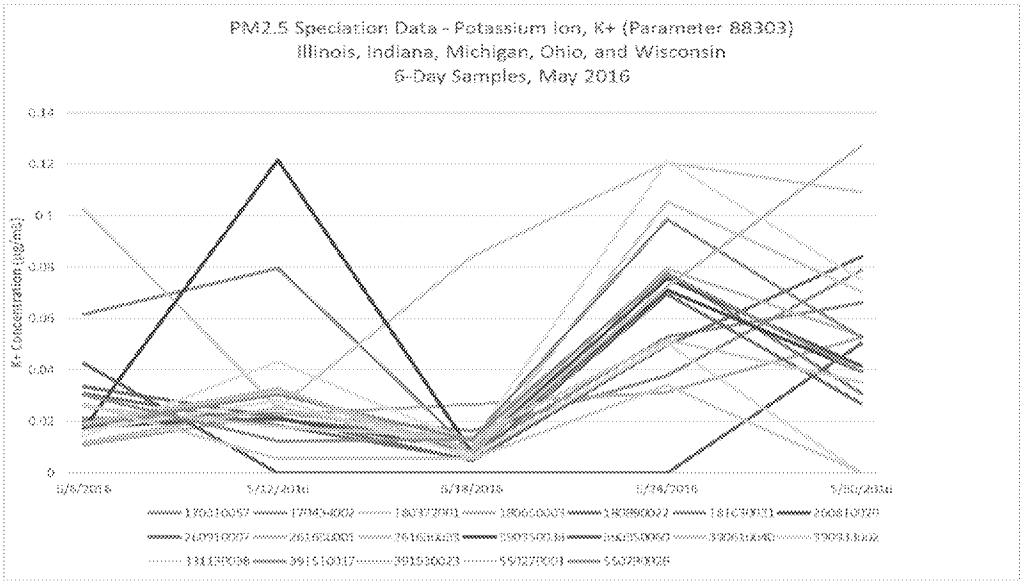
Figure 44 – $PM_{2.5}$ Speciation Data – Organic Carbon Trend in May 2016



As illustrated in the graph, the organic carbon data collected in states across the Ohio Valley and the Great Lakes all simultaneous peaked on May 24. For many of the sites, the organic carbon concentrations measured on May 24 was the highest for the entire month of May 2016.

In addition to analyzing the organic carbon data on May 24, the Department analyzed the impact that the potassium ion had during the same time period. Figure 45 displays the trend of the potassium ion at various $PM_{2.5}$ speciation monitors across the five states listed above.

Figure 45 – $PM_{2.5}$ Speciation Data – Potassium Ion Trend in May 2016



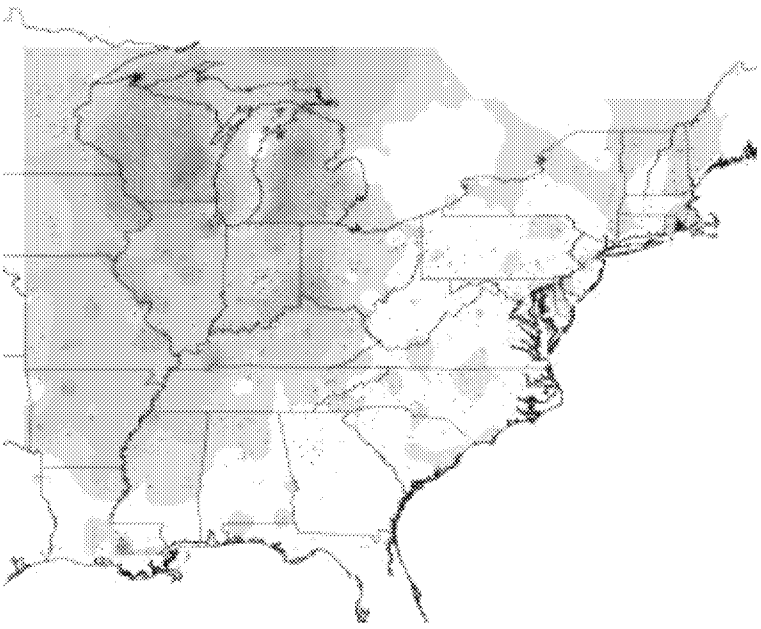
During May 2016, several monitors across the Great Lakes and Ohio Valley states saw spikes in the potassium ion. While the graph above shows various spikes throughout the period, the potassium ion did follow a similar trend to the organic carbon. After having concentrations near 0.01 ug/m3 on May 18, most of the monitors in the domain saw potassium ion concentrations spike on May 24. Like the trend in the organic carbon data, this spike in the potassium ion data coincides with the timing of the passage of the smoke laden air mass across the Great Lakes and the Ohio Valley.

Wildfire Impact in NOAA's Community Multiscale Air Quality Modeling System Model

As part of a collaboration with the U.S. EPA, NOAA has embarked on forecasting ozone formation across the continental US via use of a modeling platform. The Community Multiscale Air Quality Modeling System (CMAQ) model was used to help NOAA achieve these goals. The model requires some preprocessing work in order to run. The preprocessing includes analyzing meteorological data and emissions data. The emissions data file that is used to run NOAA's CMAQ model uses point and mobile source emissions generated from the data in the National Emissions Inventory (NEI) database. This database does not include data from current wildfires. Therefore, the results of NOAA's air quality forecast model do not take into account wildfire emissions.

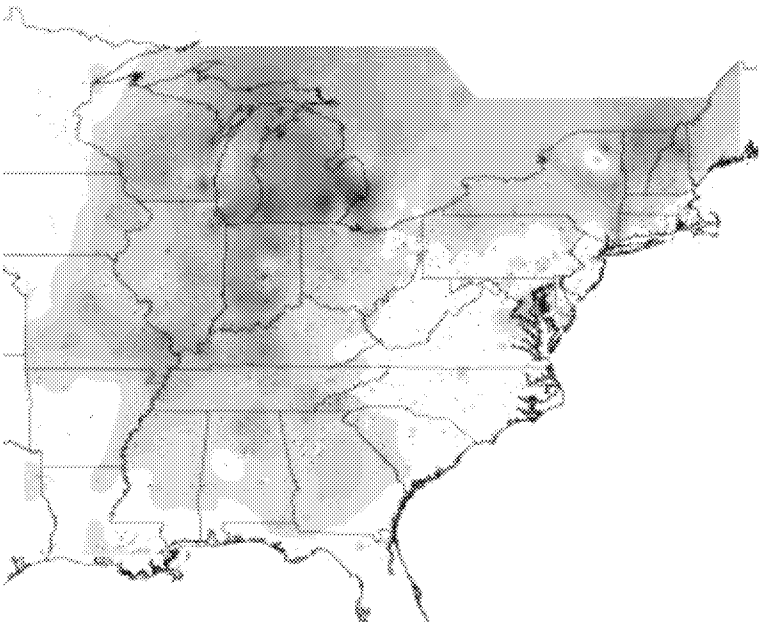
Mr. Joel Dreessen from the Maryland Department of the Environment analyzed the impact that not accounting for wildfire emissions had on NOAA's CMAQ model performance. Mr. Dreessen's analysis, outlined in Figures 46 to 48 compared the CMAQ model's predicted concentrations with actual monitored ozone concentrations during the same period. The blue areas in the maps below illustrate how the model underperformed (i.e. how much the CMAQ model underpredicted ozone concentrations when compared to actual monitored values). The red areas in the following maps illustrate how the model overperformed (i.e. how much the CMAQ model overpredicted ozone concentrations when compared to actual monitored values).

Figure 46 = NOAA CMAQ Model Performance – May 24



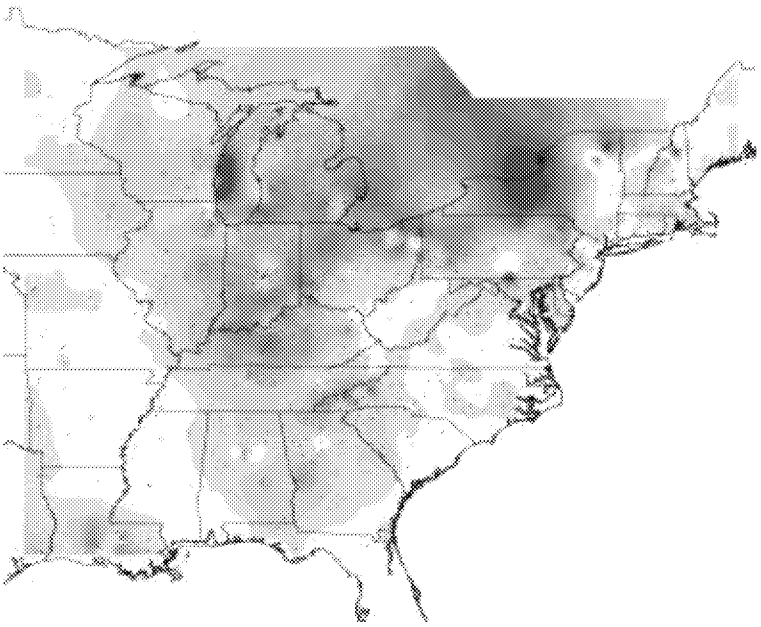
On May 24, the NOAA CMAQ forecast model underperformed across much of the Great Lakes and Ohio Valley region. Based on the Conceptual Model for Ozone Formation during the Fort McMurray fires section above, the smoke plume was over the Great Lakes on this date. Therefore, there is a direct correlation between the geographical extent of smoke plume with underprediction in NOAA's CMAQ model.

Figure 47 = NOAA CMAQ Model Performance – May 25



On May 25, the NOAA CMAQ forecast model performance was very similar to May 24's model performance. The highest underprediction, which was centered over Wisconsin on May 24, migrated east over Michigan and Indiana on May 25. By May 25, the smoke plume had shifted over the northeastern US. However, ozone concentrations in areas that had been impacted by the smoke plume earlier in the week were underpredicted.

Figure 48 = NOAA CMAQ Model Performance – May 26



On May 26, the NOAA CMAQ forecast model continued to underperform across much of the northeastern US. By May 26, the smoke plume began to make its way off the New England coastline. In its wake, ozone formation was poorly forecasted because the CMAQ model did not take into account the emissions associated with the Fort McMurray fires. The peak model underperformance was centered across New York State, with impacts extending southward across Pennsylvania and Maryland.

Similar Day Analysis

The Department has outlined the meteorological conditions that unfolded on May 24 to May 26 which contributed to the impact of the Fort McMurray fires across Pennsylvania. Similar meteorological conditions were likely not to cause an exceedance, in the absence of smoke, across the Commonwealth. As outlined in previous sections, temperatures during the smoke event were in the 80s across the Commonwealth while surface winds persisted out of the northwest (at least on May 24 and May 25). Also, an area of high pressure moved from west to east across the Mid-Atlantic. Therefore, the Department's similar day analysis focused on these three factors.

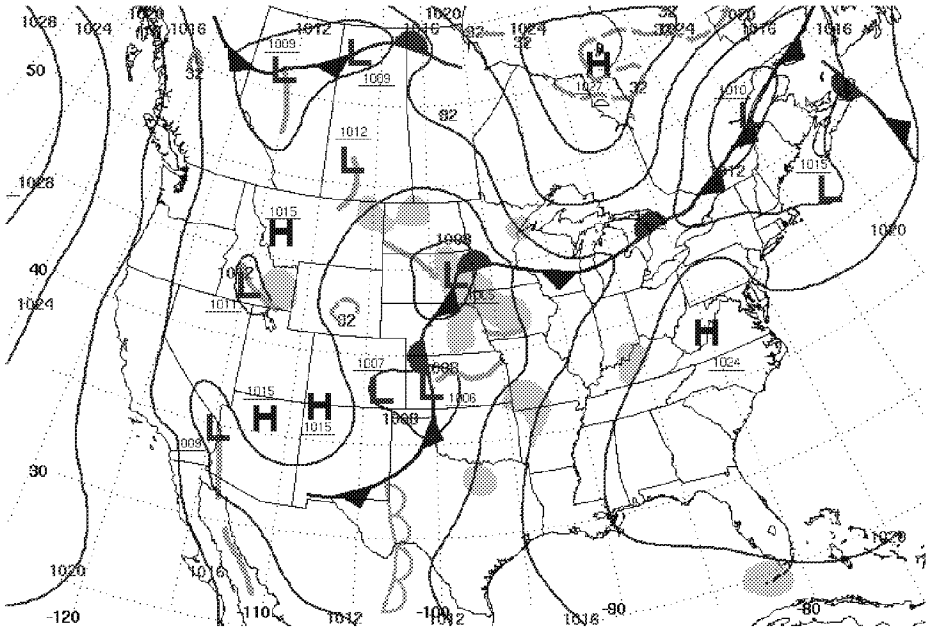
After analyzing meteorological conditions with the three factors of temperatures in the 80s, winds persisting out of the northwest, and the presence of an area of high pressure in close proximity to the Mid-Atlantic during the 2012 to 2016 period, the Department determined what days met these criteria. The Department's similar day analysis ultimately focused on two days: May 26, 2014 and May 4, 2015 when compared with the meteorological conditions which occurred on May 25, 2016.

In Table 4 below, maximum temperatures for the three days are outlined for three sites: Erie, Harrisburg and Philadelphia. In addition, NOAA's surface analysis maps from 8 AM are outlined for the May 25, 2016, May 25, 2014 and May 5, 2015 dates in Figures 49, 50 and 51, respectively. In addition, U.S. EPA AirNow's daily peak 8-hour ozone concentrations maps are outlined for the May 25, 2016, May 26, 2014 and May 4, 2015 dates in Figures 52, 53 and 54, respectively.

Table 4 – Maximum Temperatures for Three Pennsylvania Cities on Three Different May Days

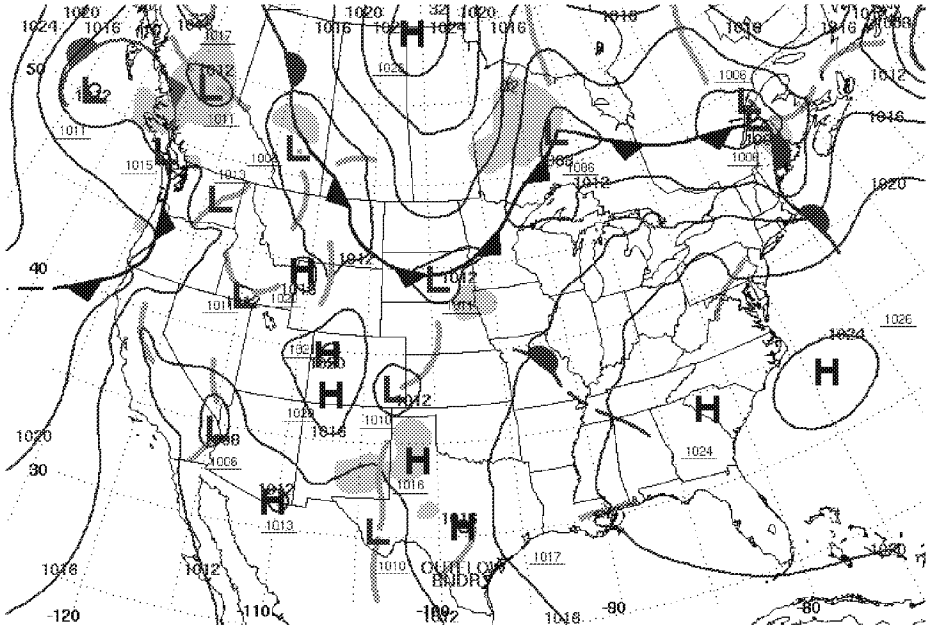
City	Airport	5/25/2016	5/26/2014	5/4/2015
Erie, PA	KERI	82	78	81
Harrisburg, PA	KMDT	85	84	84
Philadelphia, PA	KPHL	88	87	85

Figure 49 – NOAA Surface Analysis on May 25, 2016 at 8 AM EDT



Surface Weather Map at 7:00 A.M. E.S.T.

Figure 50 – NOAA Surface Analysis on May 26, 2014 at 8 AM EDT



Surface Weather Map at 7:00 A.M. E.S.T.

Figure 51 – NOAA Surface Analysis on May 4, 2015 at 8 AM EDT

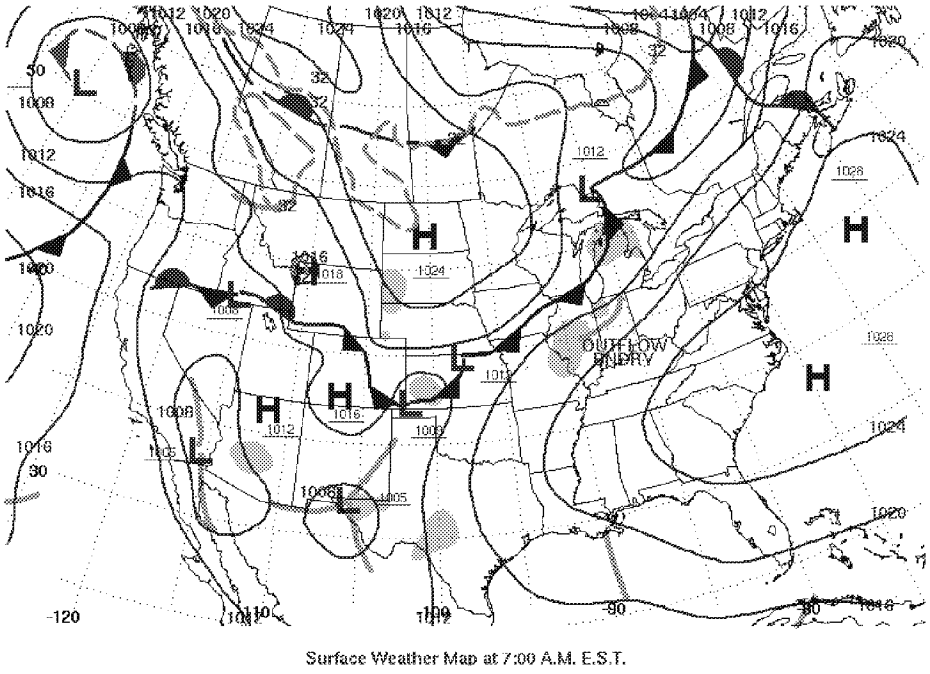


Figure 52 – Peak Ozone Concentrations in Pennsylvania – May 25, 2016

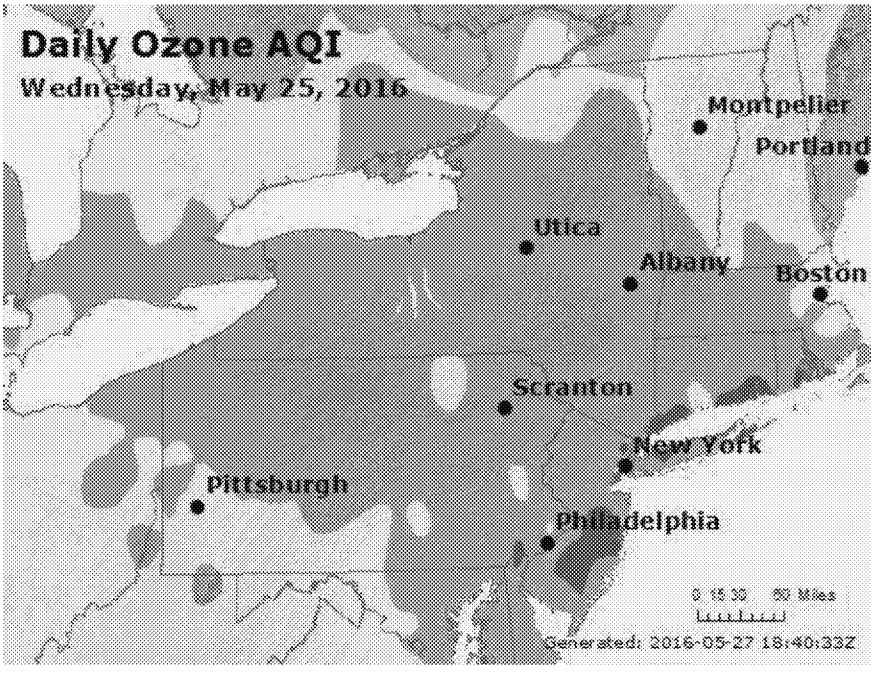


Figure 53 – Peak Ozone Concentrations in Pennsylvania – May 26, 2014

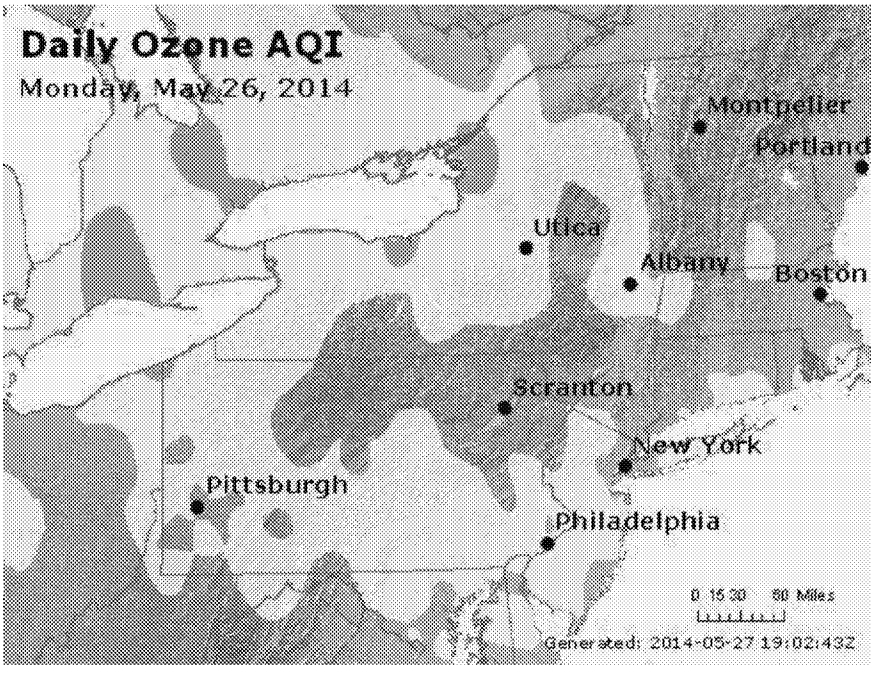
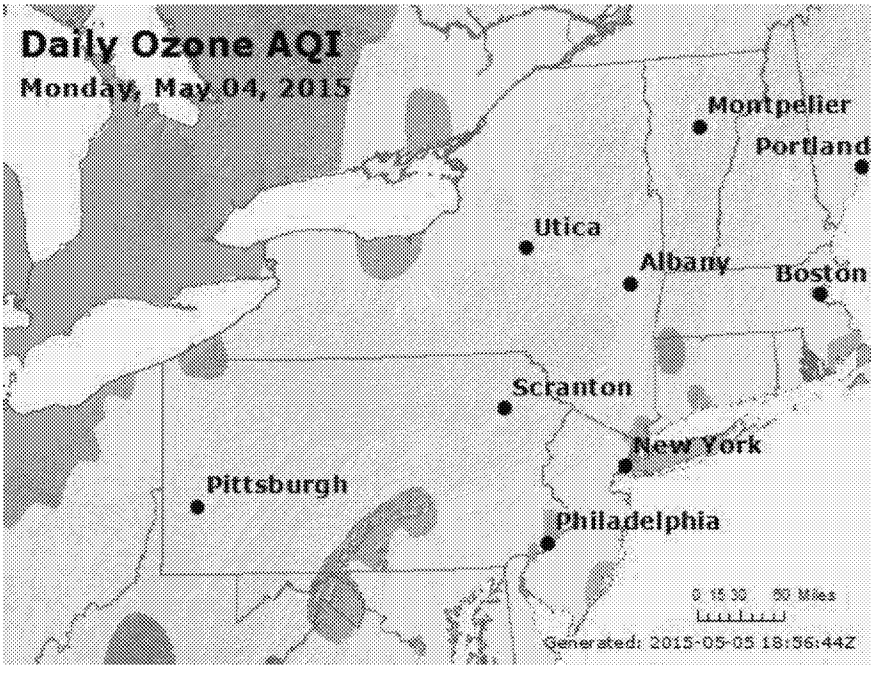


Figure 54 – Peak Ozone Concentrations in Pennsylvania – May 4, 2015



Overall, even though the three days outlined as part of the similar day analysis were meteorologically similar, the maximum 8-hour ozone concentrations across the Commonwealth were vastly different. In the other two case study examples, there was not one monitor in Pennsylvania which exceeded the 2015 ozone NAAQS.

The Occurrence was a Natural Event

Within 40 CFR 50.14, an exceptional event demonstration must include a justification stating that "the event was a human activity that is unlikely to recur at a particular location or was a natural event." According to a news report from the Weather Network, wildfire investigators ruled out lightning as the cause of the Fort McMurray fires. By process of elimination, human activity was blamed to causing the fires. Even with that being case, in the past, U.S. EPA has acknowledged that the treatment of wildfire on wildland (which is what surrounds the city of Fort McMurray, Alberta, Canada) can be considered a natural event because it is consistent with language within the Clean Air Act (CAA) and the Exceptional Events Rule. Based on guidelines set forth in 40 CFR 50.1 (o), a wildland is "an area in which human activity and development are essentially non-existent…" This definition describes the area surrounding the city of Fort McMurray to a tee. With the location of the wildfire being in a wildland, the Department feels this meets the regulatory definition of a natural event (set forth in 40 CFR 50.1 (k)) and therefore has demonstrated that the event is a natural event and may be considered for treatment as an exceptional event.

The Occurrence was Not Reasonably Controllable or Preventable

As outlined above, the Department believes these fires constitute a natural event as it relates to the language within the CAA and the Exceptional Events Rule. Since these fires occurred outside of the US, the Department believes these fires could not be reasonably controlled or prevented by the Commonwealth of Pennsylvania. No policy that Pennsylvania could have enacted would have prevented the fire and its associated plumes of smoke from transporting across the northern US into Pennsylvania. In addition, Pennsylvania is unaware of any evidence which demonstrates that preventing or controlling impacts beyond those that actually occurred would have been reasonable. As a result, emissions from the Fort McMurray fires were not reasonably controllable or preventable, illustrating that this event can be considered for treatment as an exceptional event.

Public Comment Process

Pursuant to 40 CFR 50.14, the Department is required to post this documentation for public notice for a period of 30 days to solicit comments from the public. After conclusion of the public comment period, the Department will respond to all comments and incorporate a comment and response document as part of the document.

Conclusions

In conclusion, based on the Department's in-depth analysis into the contributions of high ozone across the Commonwealth on May 24 to May 26, 2016, the Department feels that transport of smoke associated with the Fort McMurray fires in Alberta, Canada, contributed to the elevated ozone concentrations. Utilizing factors such as surface and upper air meteorology, satellite imagery, and pollutant data (ozone and fine particulates), the Department was able to successfully determine that the smoke plume associated with the Fort McMurray fires had an impact on ozone formation across the Commonwealth. Specifically, the details outlined in Sections 2 and 3 of this document support the Department's position that the Fort McMurray fires affected air quality across the Commonwealth in such a way that a clear causal relationship between the Fort McMurray fires and ozone monitored exceedances exists on May 24, May 25, and May 26, therefore satisfying the clear causal relationship criterion as it relates to exceptional events.

The Department's belief is that by following the guidelines set forth within the October 2016 revised Exceptional Event Rule, the Department was able to document its findings as it relates to the Fort McMurray fire's impact on surface based ozone concentrations. Therefore, the Department is requesting that the U.S. EPA concur with this request and allow the first through fourth high ozone concentrations of the monitors outlined in Tables 1 and 2 from May 24 to May 26, 2016 be flagged as exceptional event data, thereby excluding those days for consideration when determining the attainment status of these monitors as they relate to the 2015 ozone NAAQS.

Appendix A – Maximum Ozone Concentrations

The following figures in Appendix A display daily maximum 8-hour ozone concentrations during the 2012 – 2016 ozone seasons. These figures are referenced in the "Historical Monitoring Data Analysis" section of this document, and are presented by order of AQS site codes, as listed in Table 2 of his document

Figure A-1 – Arendtsville, PA Daily Ozone Season Maximums (2012-2016)

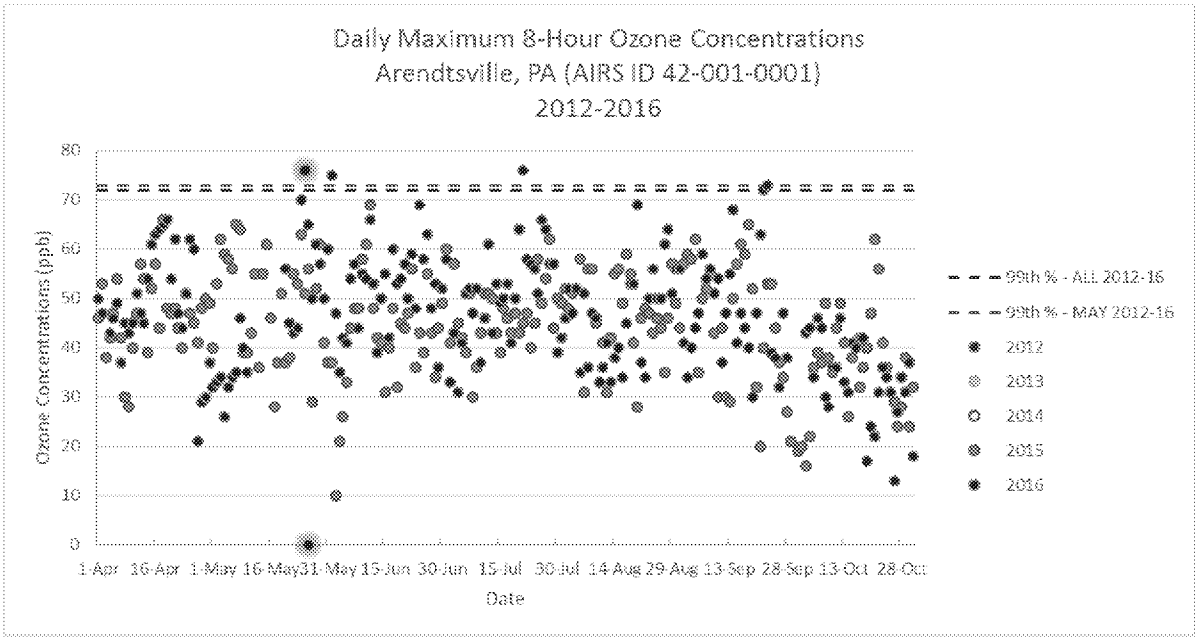


Figure A-2 – Kittanning, PA Daily Ozone Season Maximums (2012-2016)

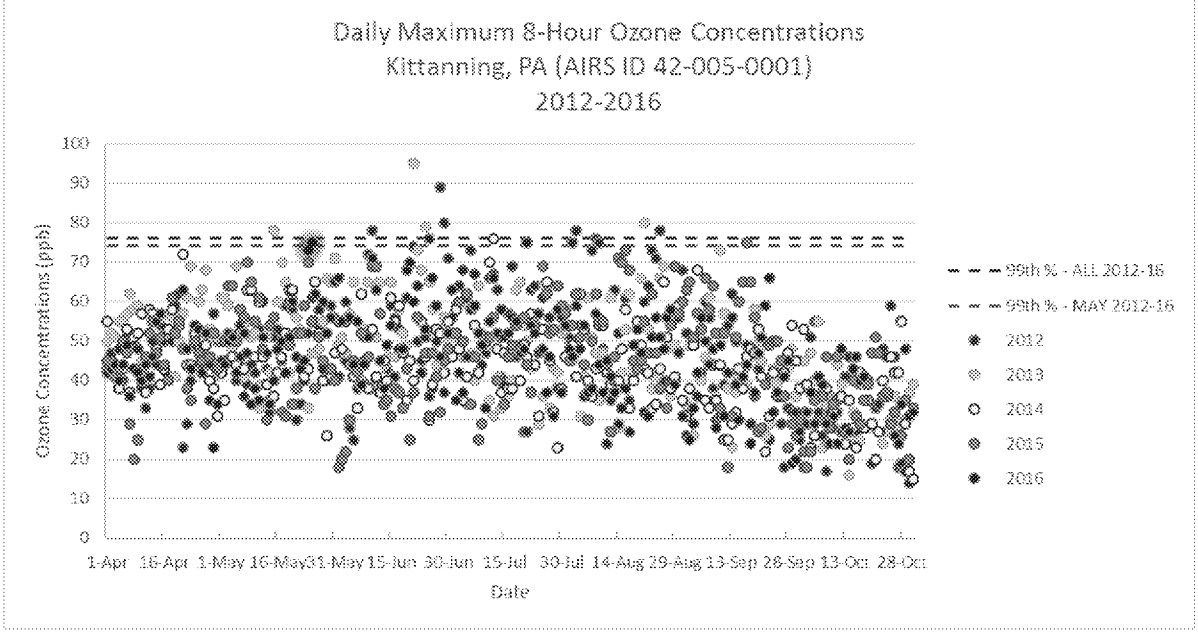


Figure A-3 – Hookstown, PA Daily Ozone Season Maximums (2012-2016)

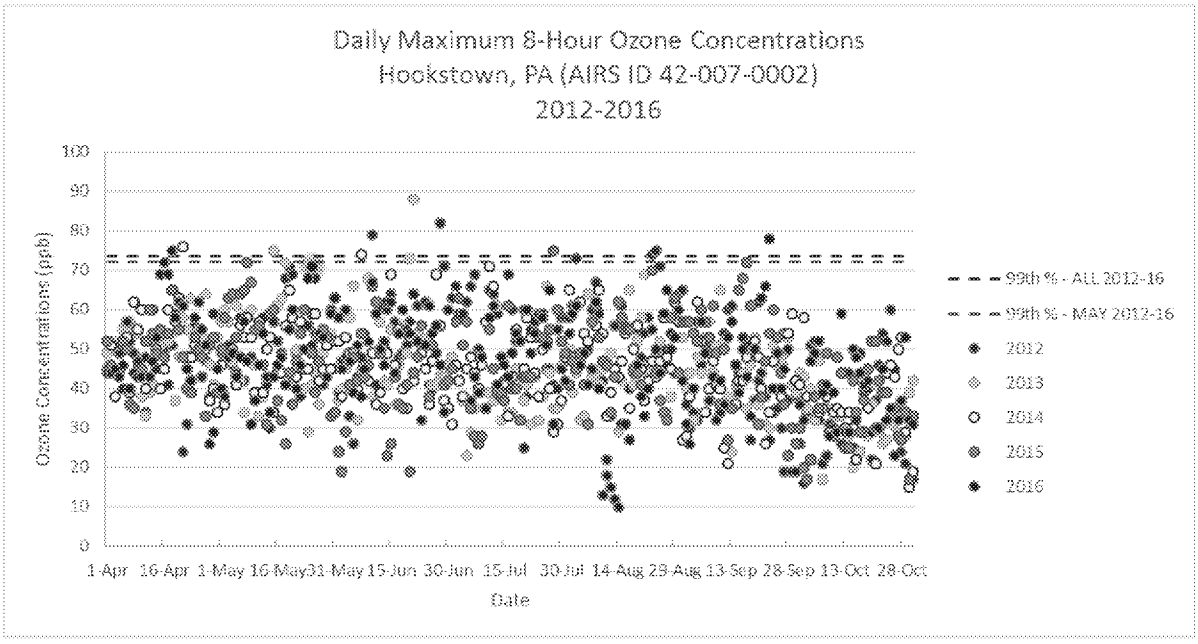


Figure A-4 – Brighton Township, PA Daily Ozone Season Maximums (2012-2016)

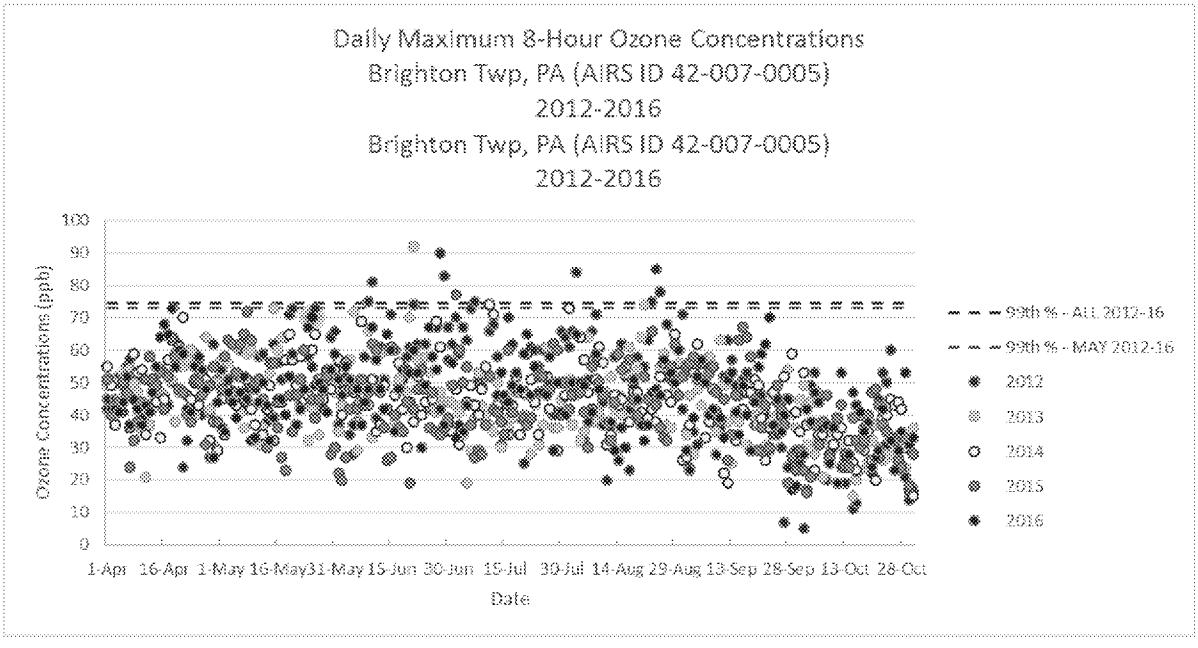


Figure A-5 – Beaver Falls, PA Daily Ozone Season Maximums (2012-2016)

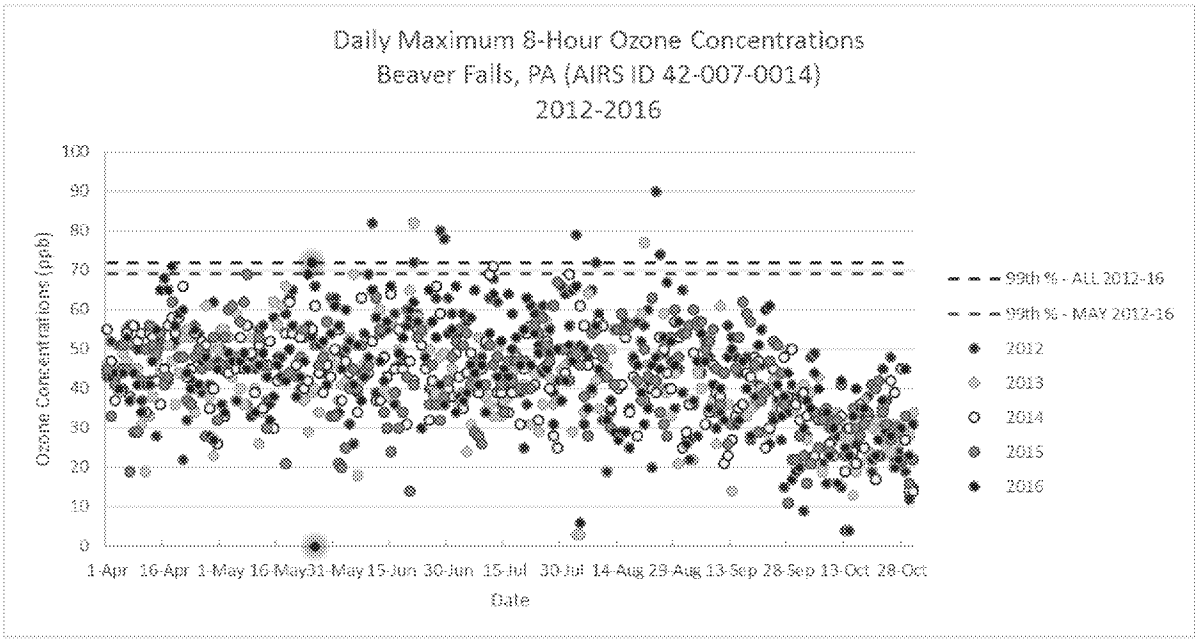


Figure A-6 – Kutztown, PA Daily Ozone Season Maximums (2012-2016)

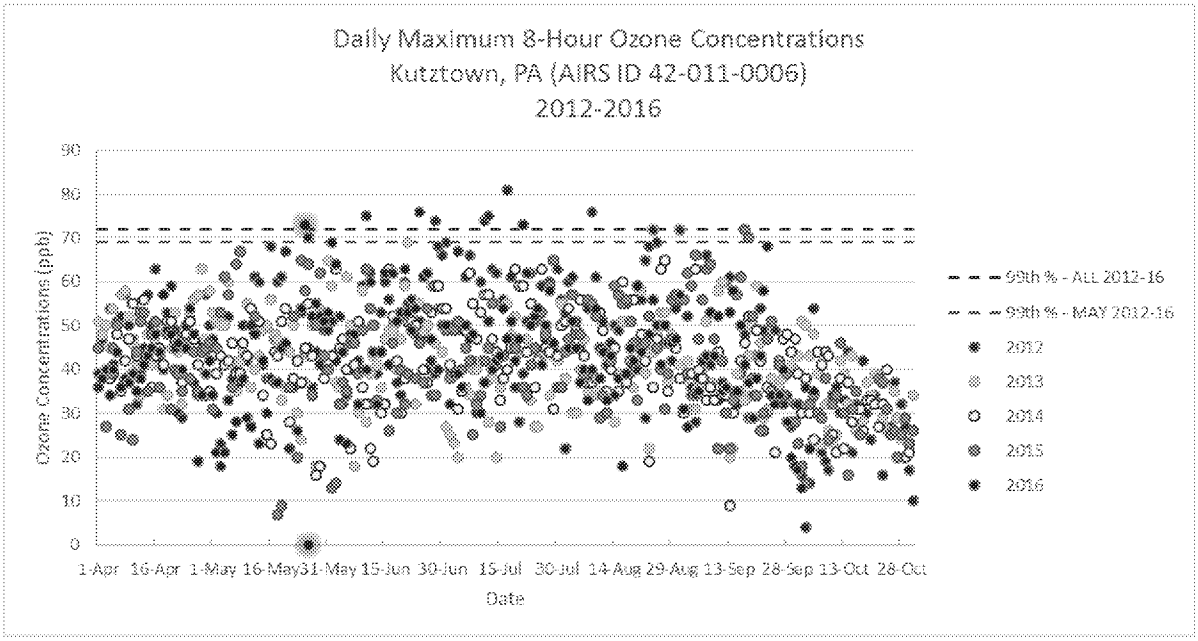


Figure A-7 – Kutztown, PA Daily Ozone Season Maximums (2012-2016)

Figure A-8 – Kutztown, PA Daily Ozone Season Maximums (2012-2016)

Figure A-9 – Kutztown, PA Daily Ozone Season Maximums (2012-2016)

Figure A-10 – Altoona, PA Daily Ozone Season Maximums (2012-2016)

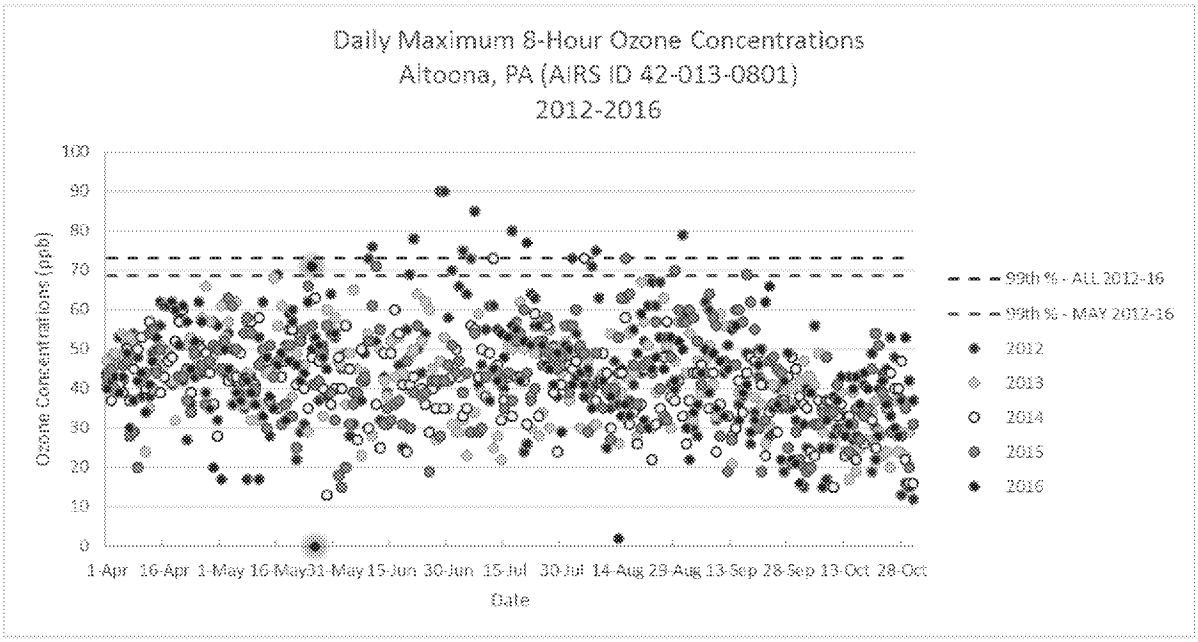


Figure A-11 – Towanda, PA Daily Ozone Season Maximums (2012-2016)

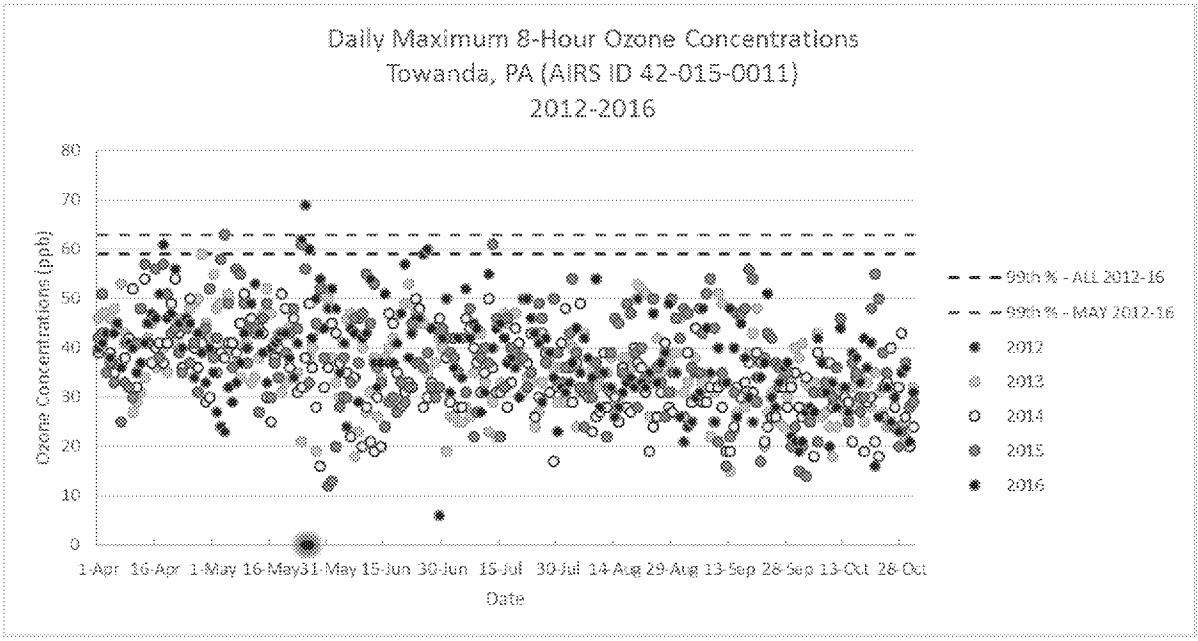


Figure A-12 – Bristol, PA Daily Ozone Season Maximums (2012-2016)

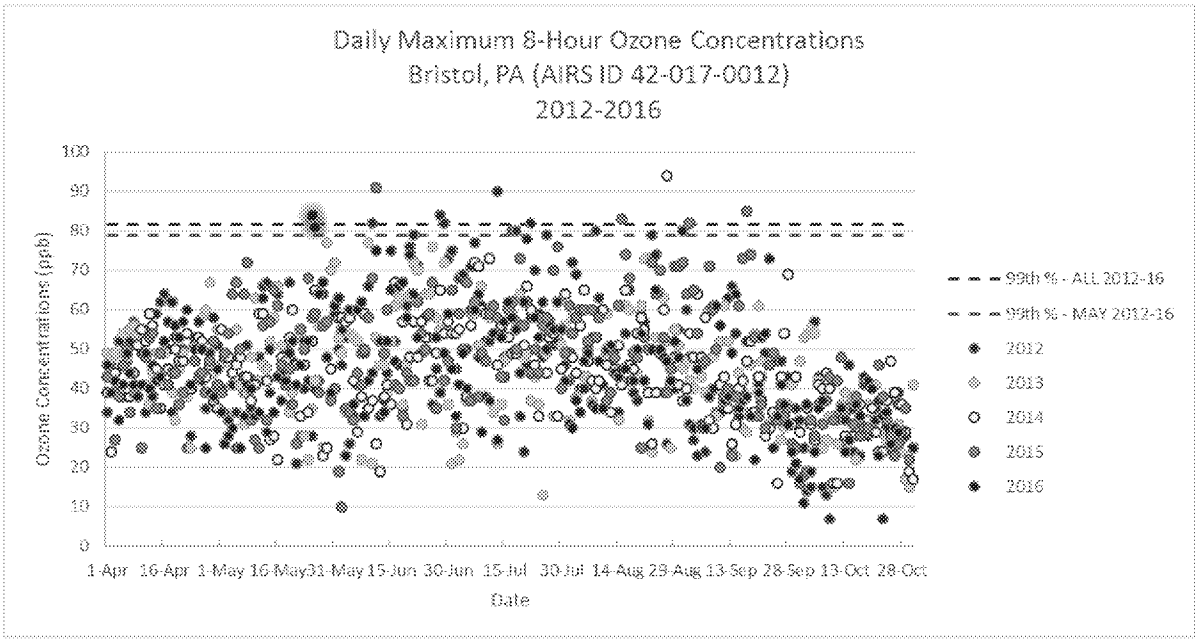


Figure A-13 – Johnstown, PA Daily Ozone Season Maximums (2012-2016)

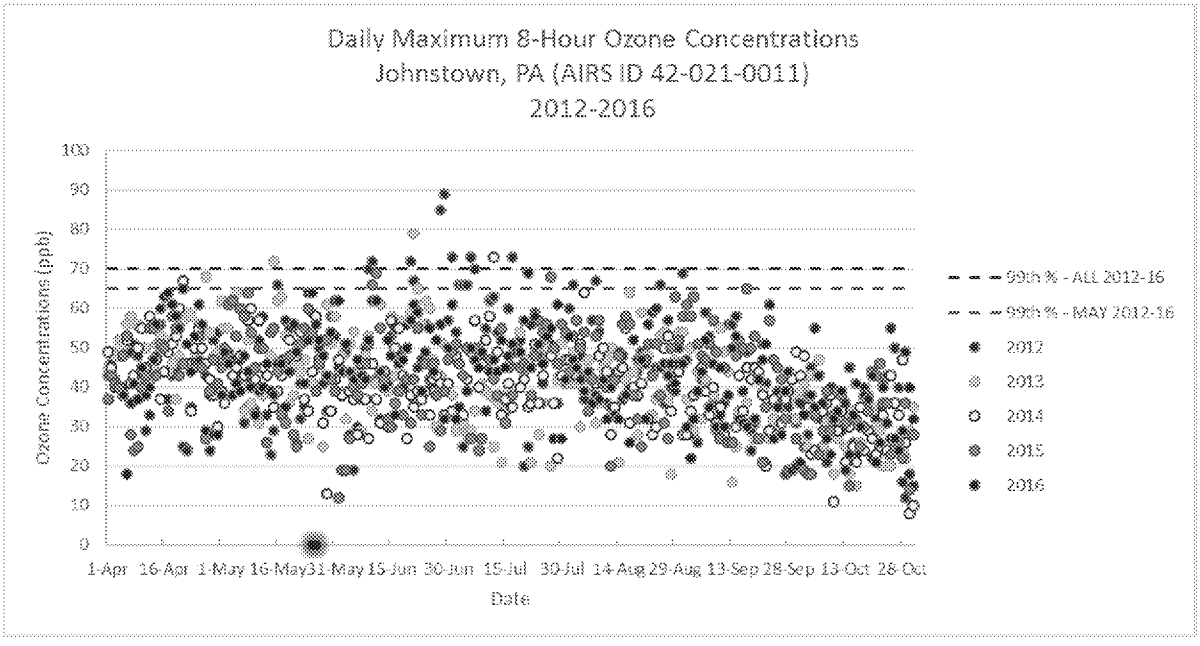


Figure A-14 – State College, PA Daily Ozone Season Maximums (2012-2016)

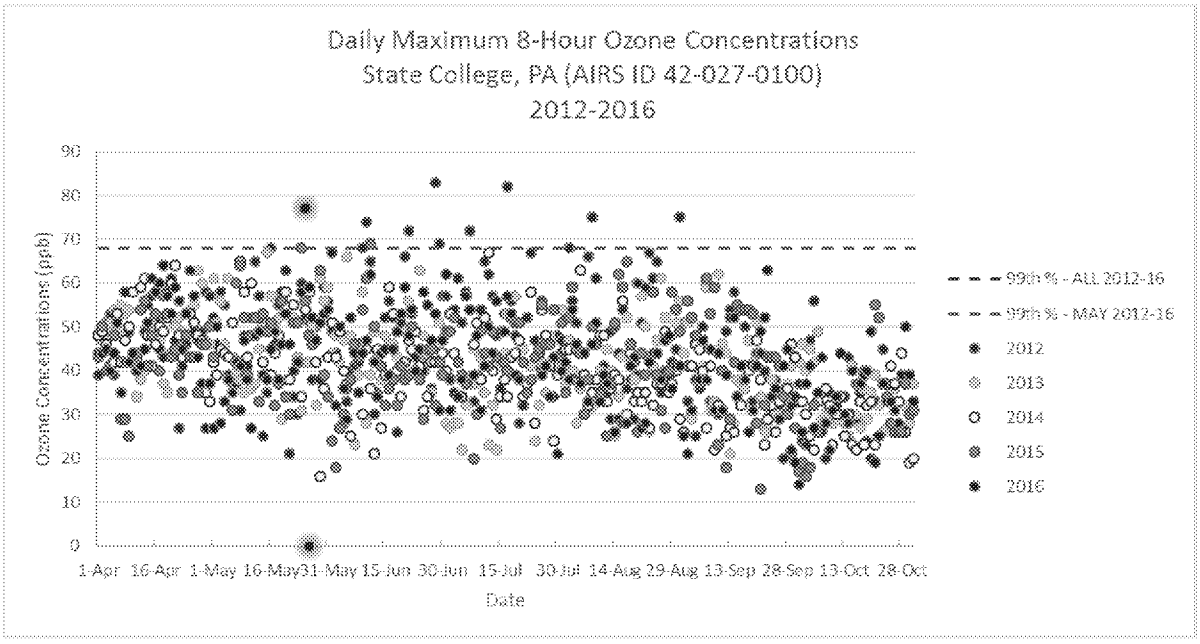


Figure A-15 – New Garden, PA Daily Ozone Season Maximums (2012-2016)

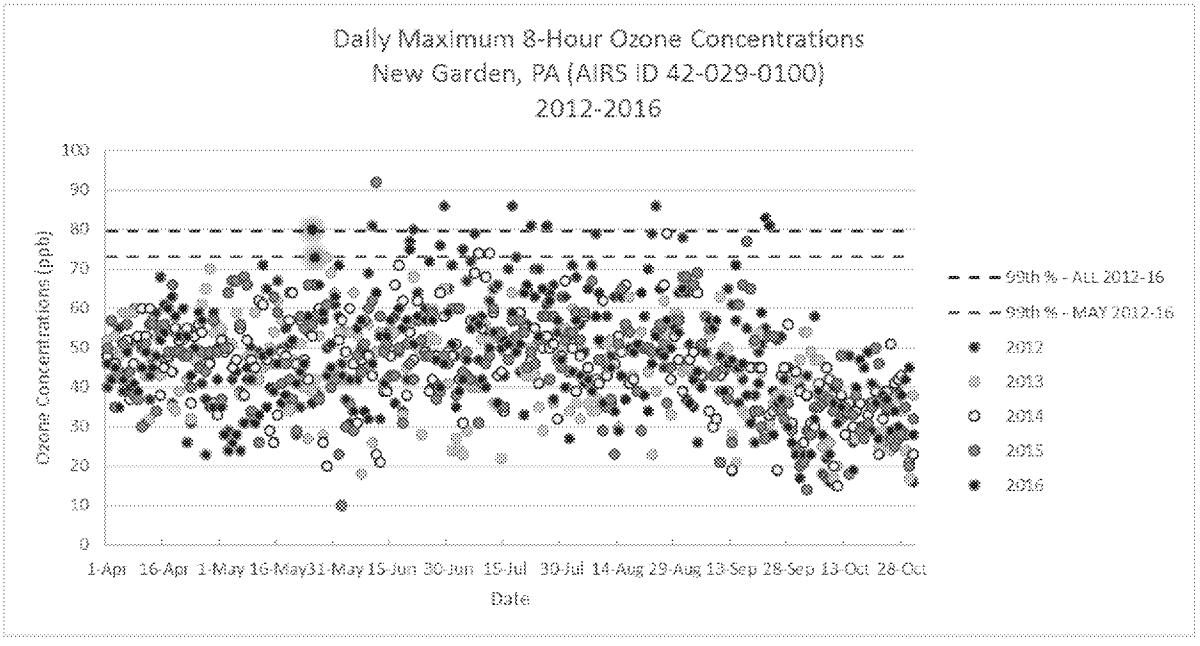


Figure A-16 – Moshannon, PA Daily Ozone Season Maximums (2012-2016)

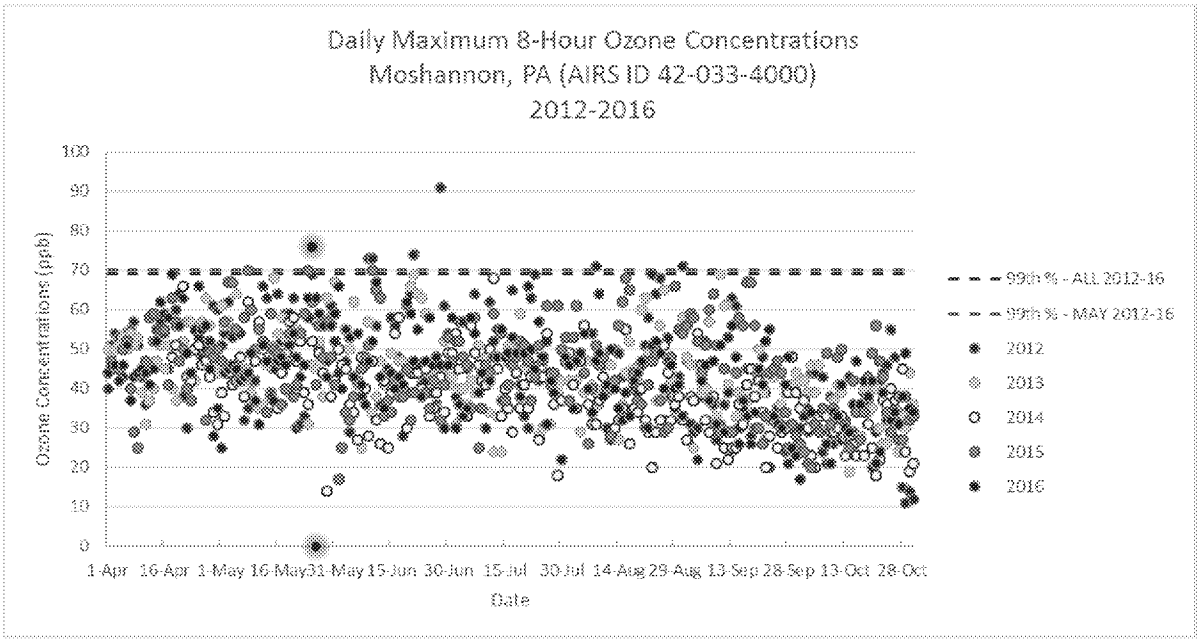


Figure A-17 – Harrisburg, PA Daily Ozone Season Maximums (2012-2016)

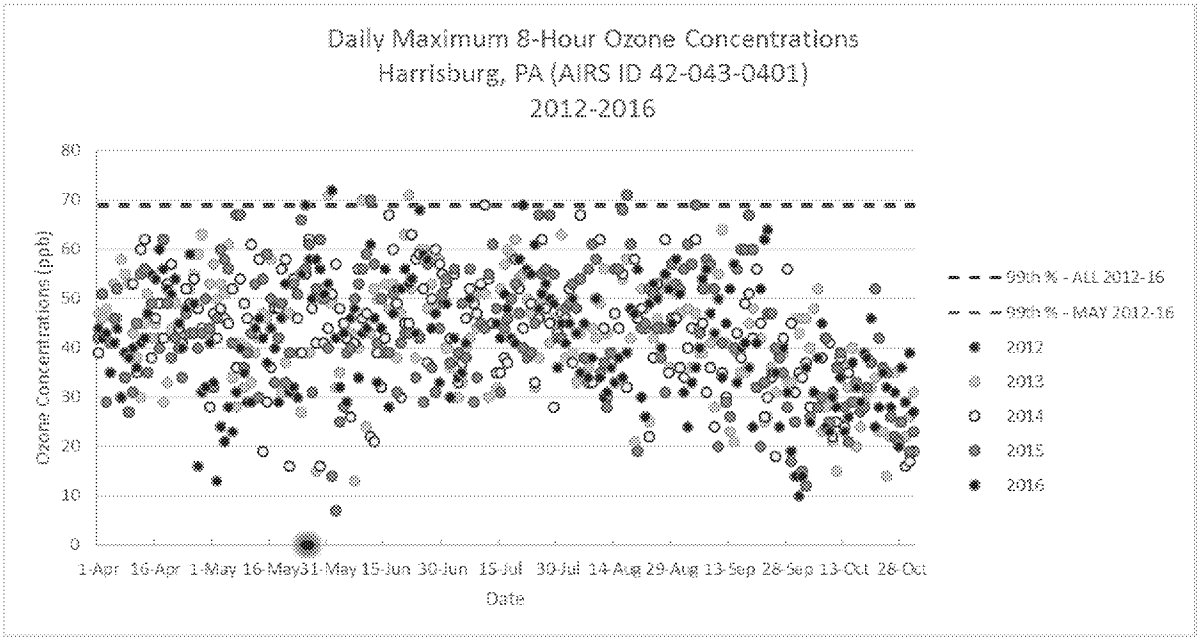


Figure A-18 – Hershey, PA Daily Ozone Season Maximums (2012-2016)

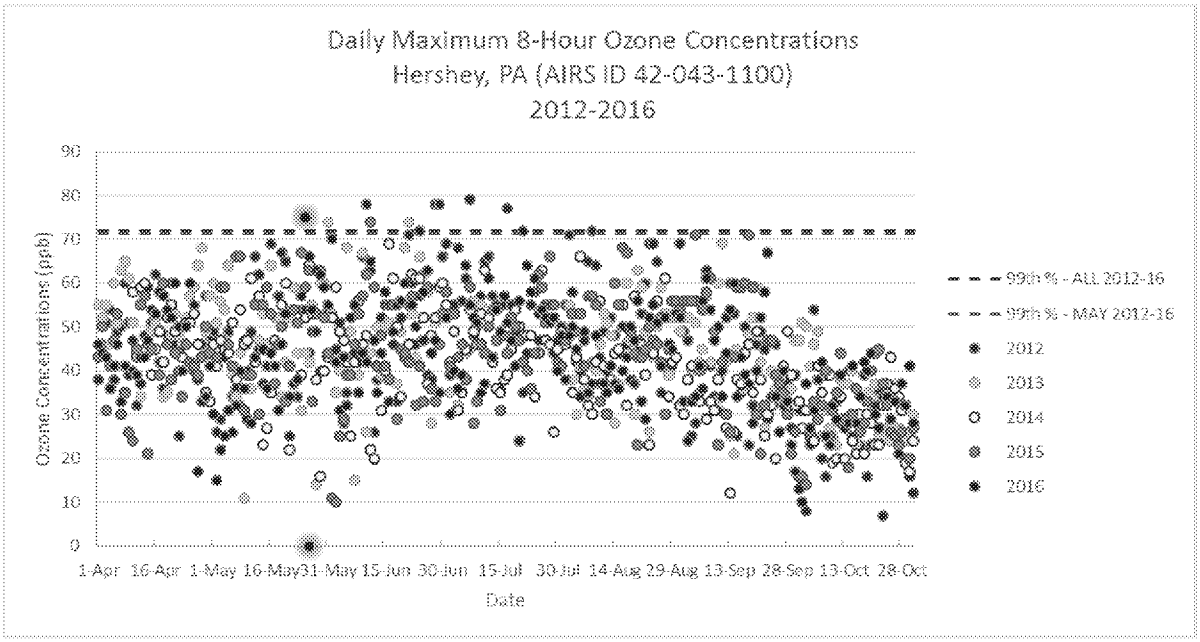


Figure A-19 – Chester, PA Daily Ozone Season Maximums (2012-2016)

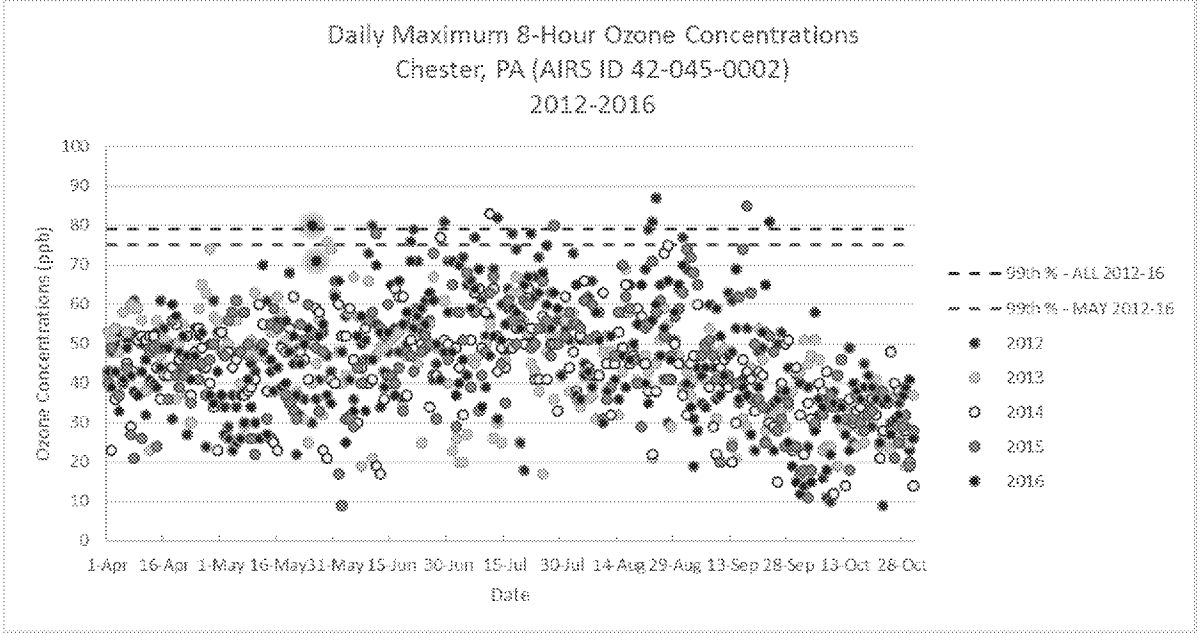


Figure A-20 – Erie, PA Daily Ozone Season Maximums (2012-2016)

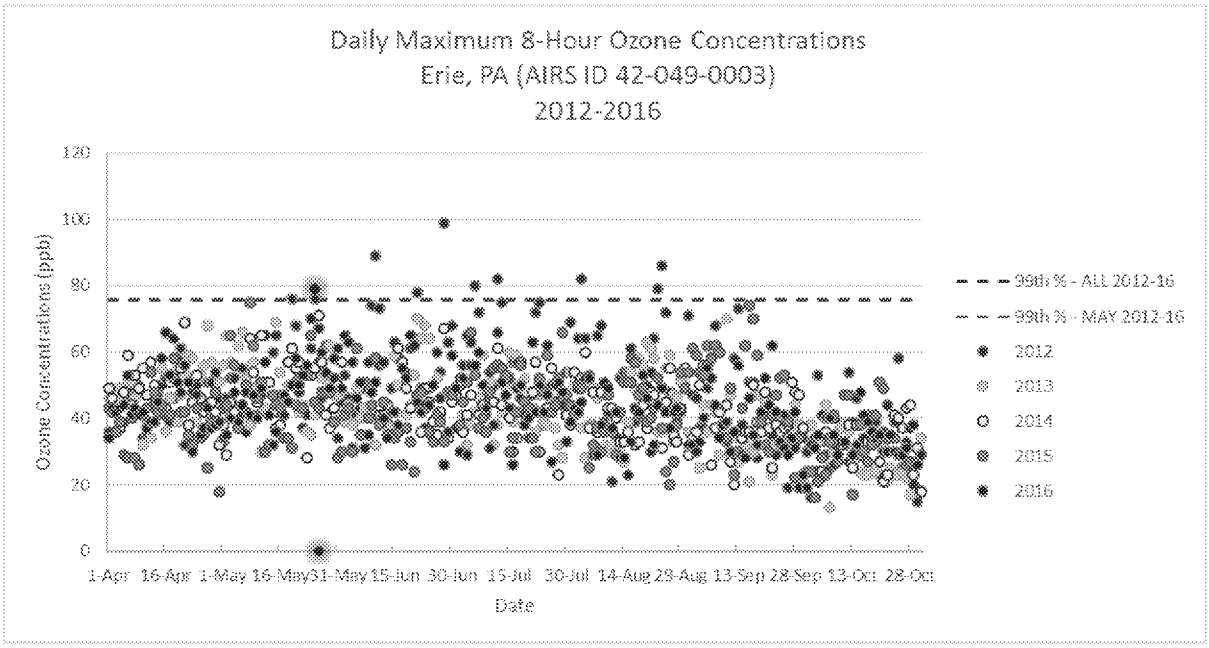


Figure A-21 – Methodist Hill, PA Daily Ozone Season Maximums (2012-2016)

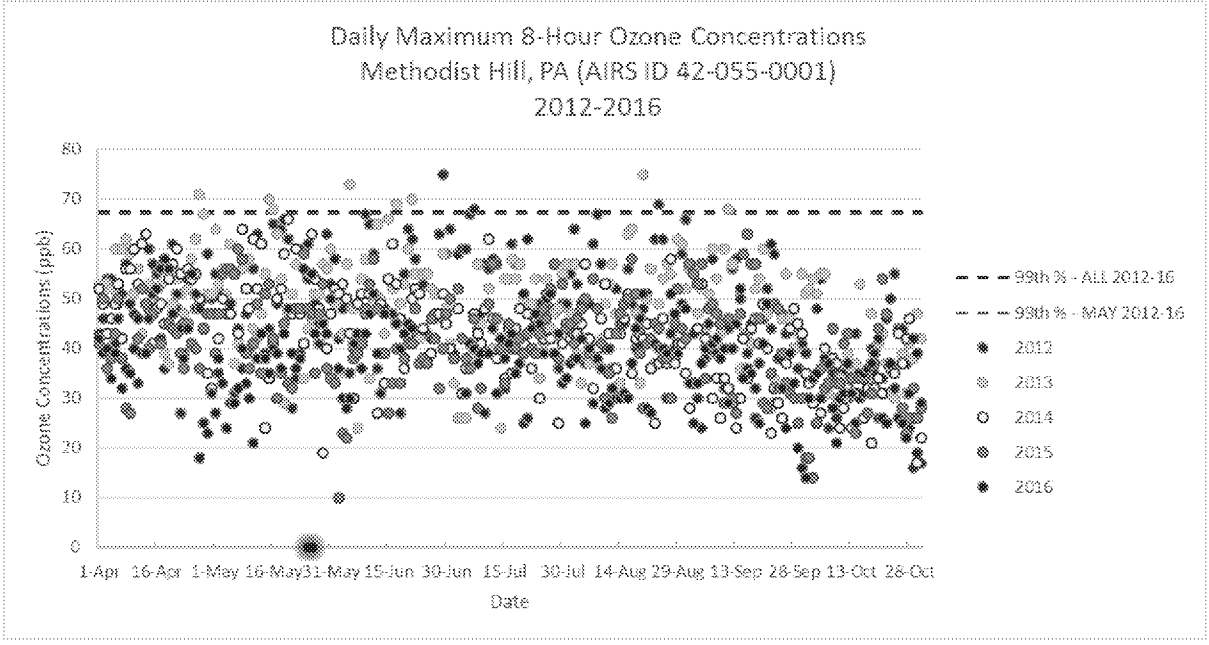


Figure A-22 – Holbrook, PA Daily Ozone Season Maximums (2012-2016)

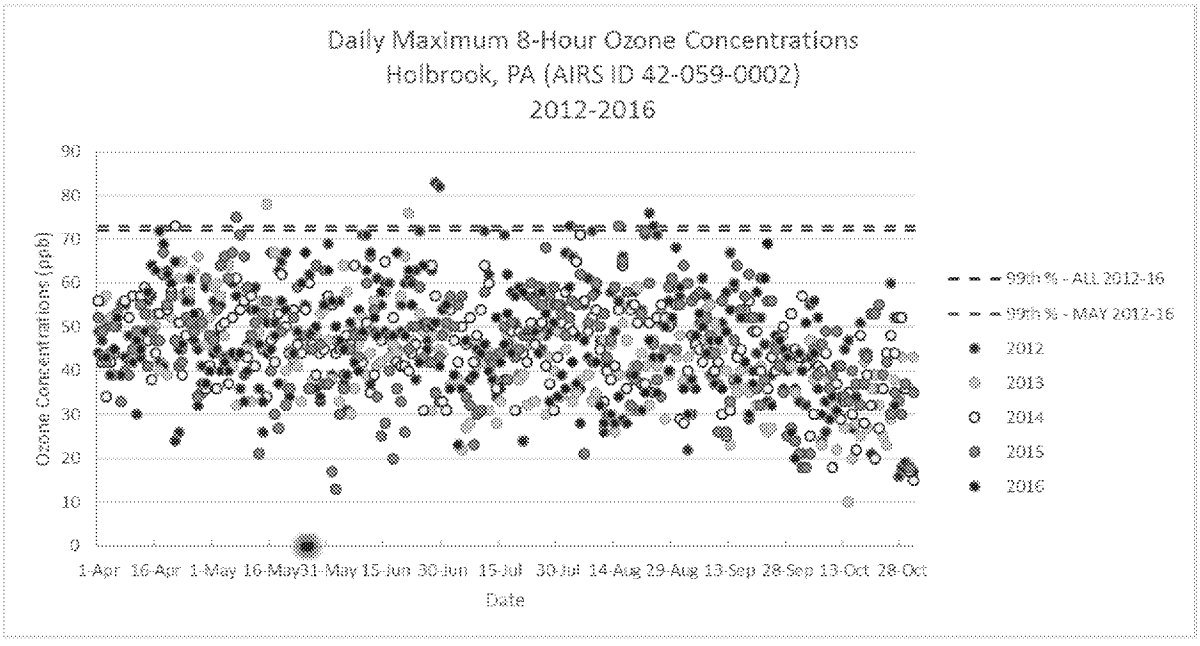


Figure A-23 – Strongstown, PA Daily Ozone Season Maximums (2012-2016)

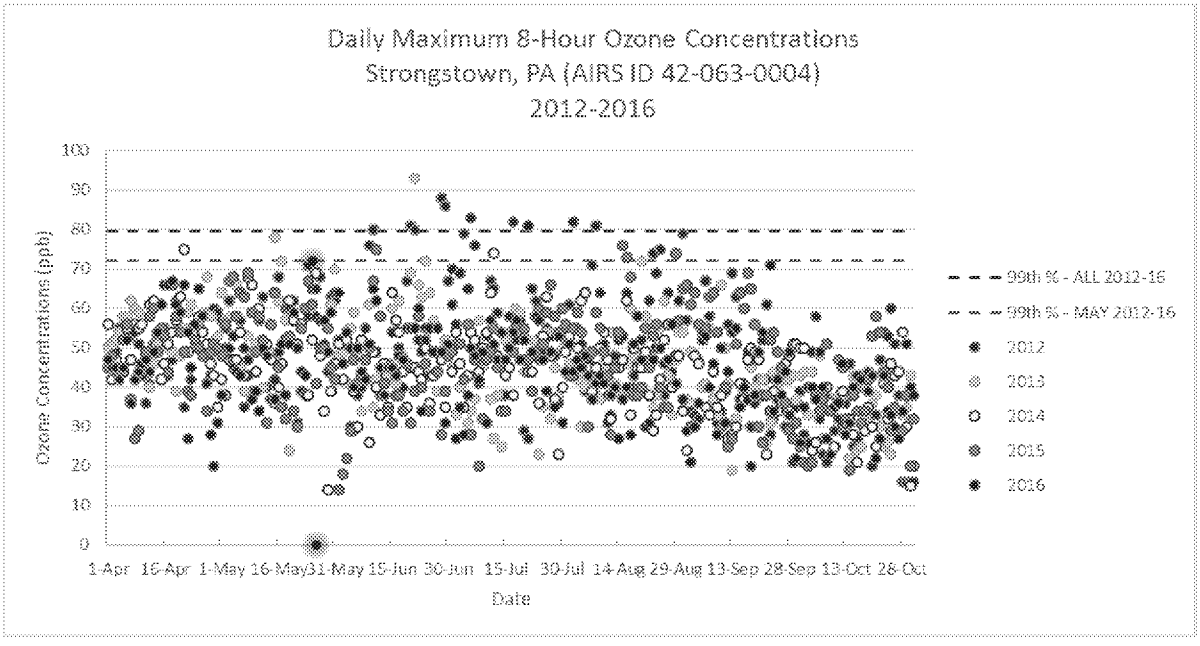


Figure A-24 – Peckville, PA Daily Ozone Season Maximums (2012-2016)

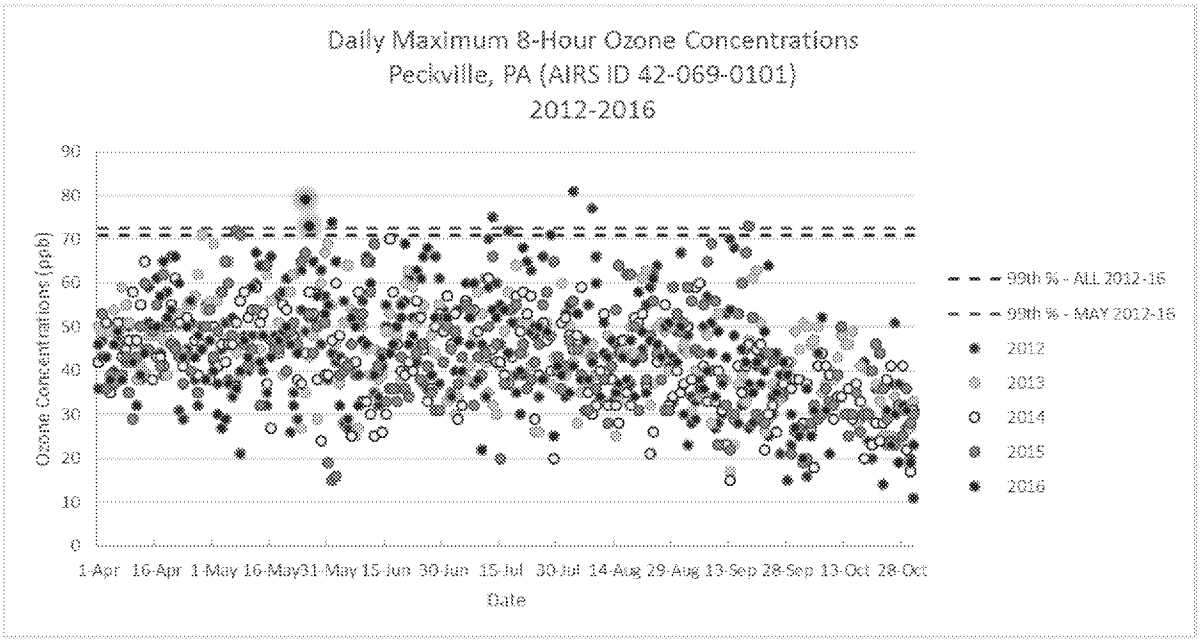


Figure A-25 – Scranton, PA Daily Ozone Season Maximums (2012-2016)

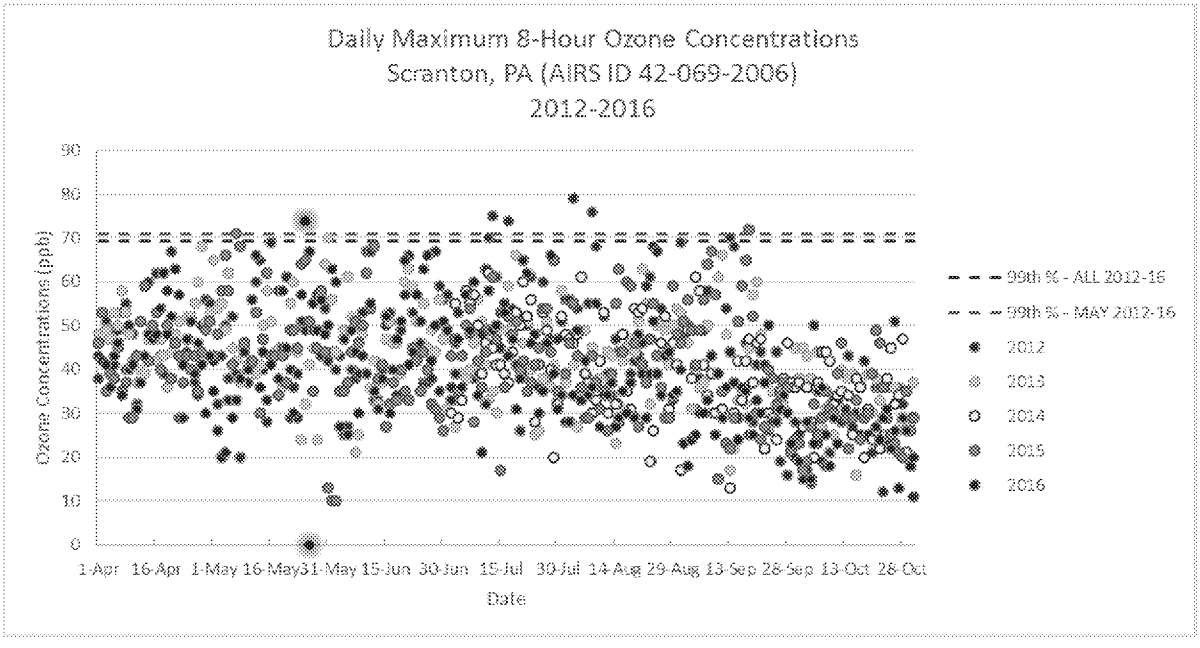


Figure A-26 – Lancaster, PA Daily Ozone Season Maximums (2012-2016)

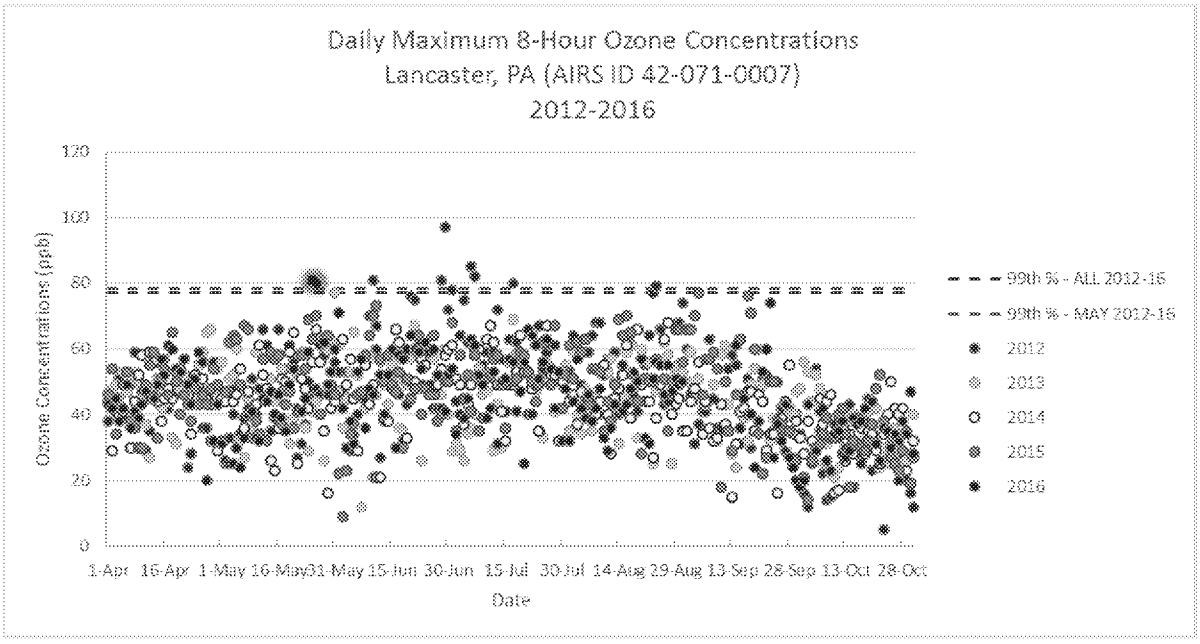


Figure A-27 – Lancaster Downwind, PA Daily Ozone Season Maximums (2012-2016)

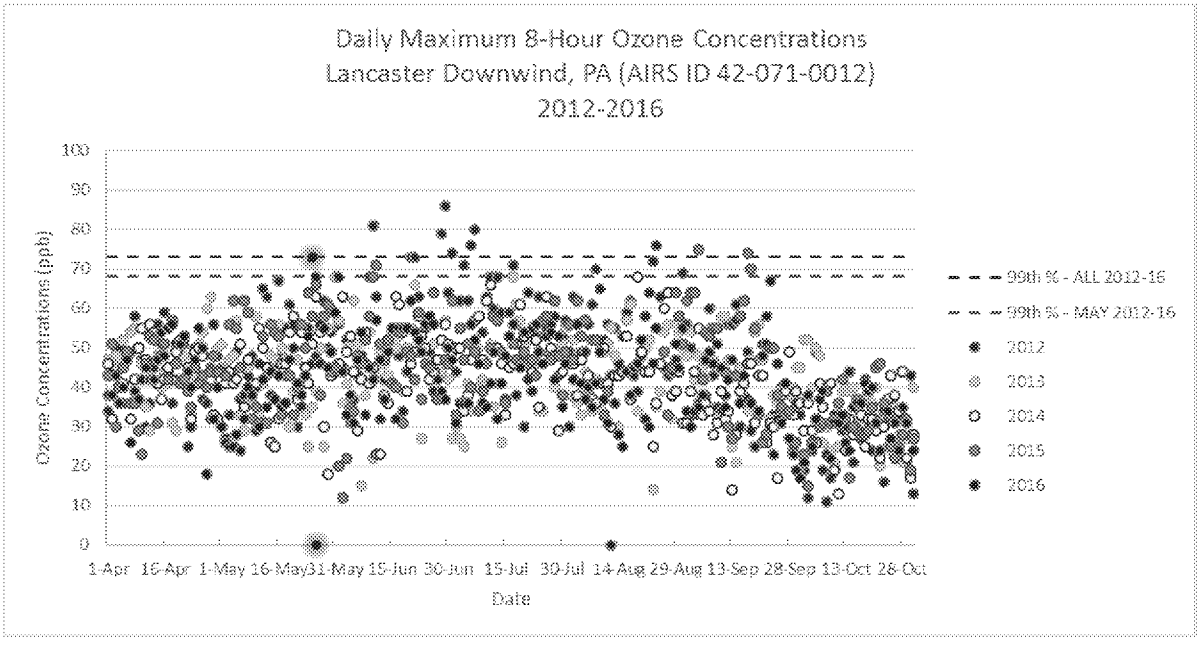


Figure A-28 – New Castle, PA Daily Ozone Season Maximums (2012-2016)

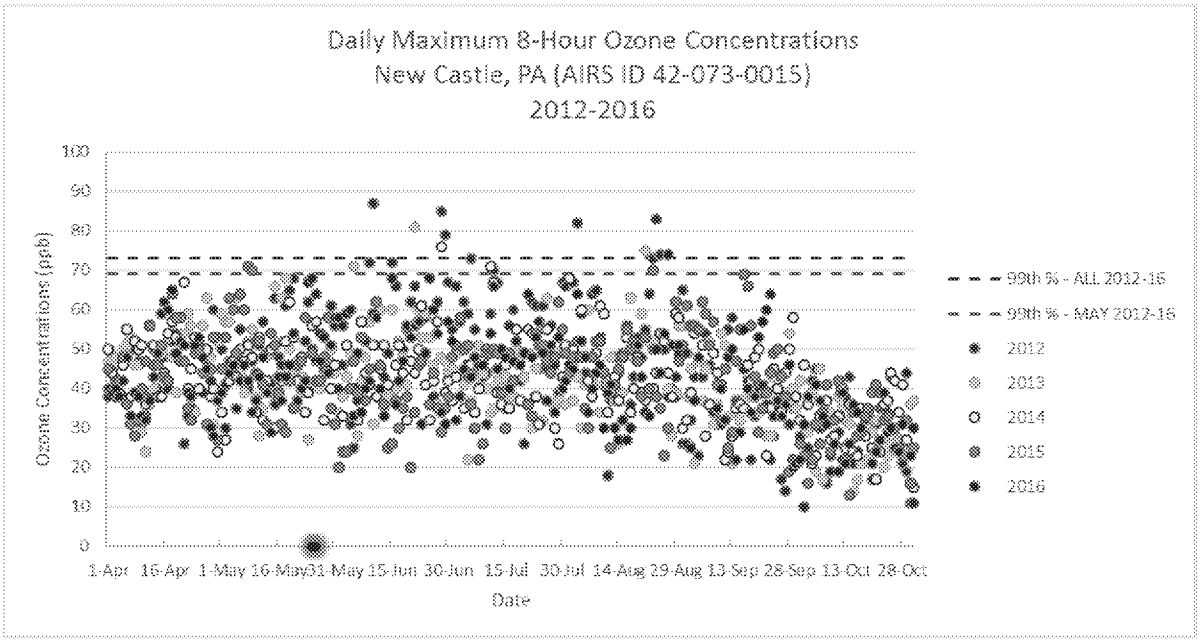


Figure A-29 – Allentown, PA Daily Ozone Season Maximums (2012-2016)

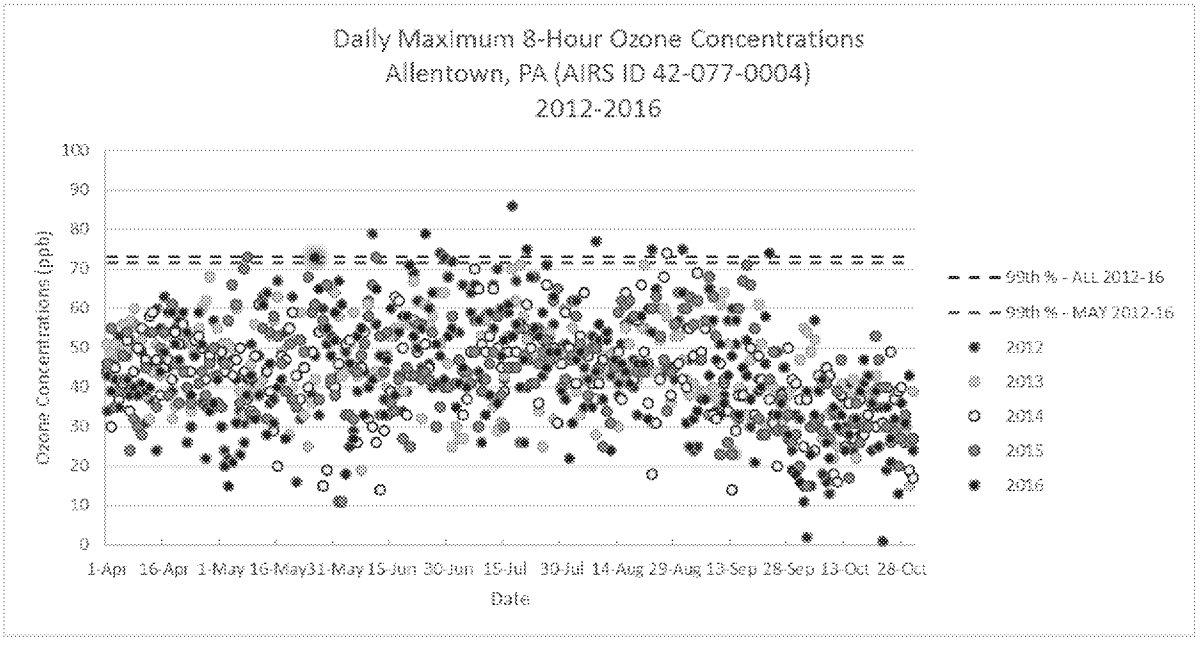


Figure A-30 Wilkes-Barre, PA Daily Ozone Season Maximums (2012-2016)

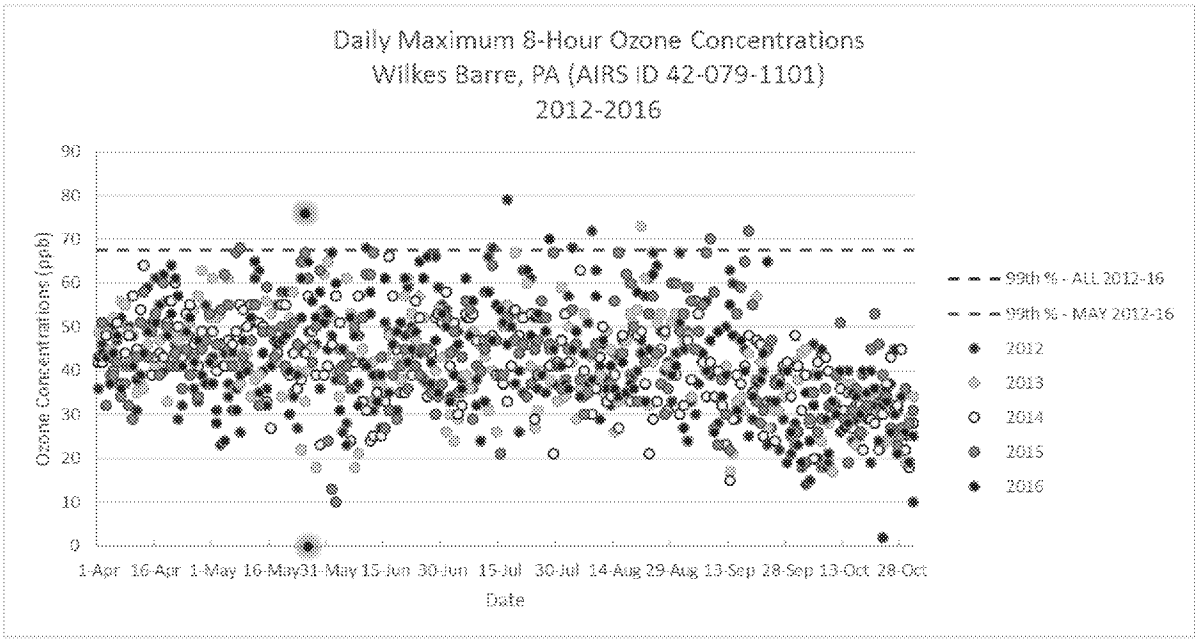


Figure A-31 – Montoursville, PA Daily Ozone Season Maximums (2012-2016)

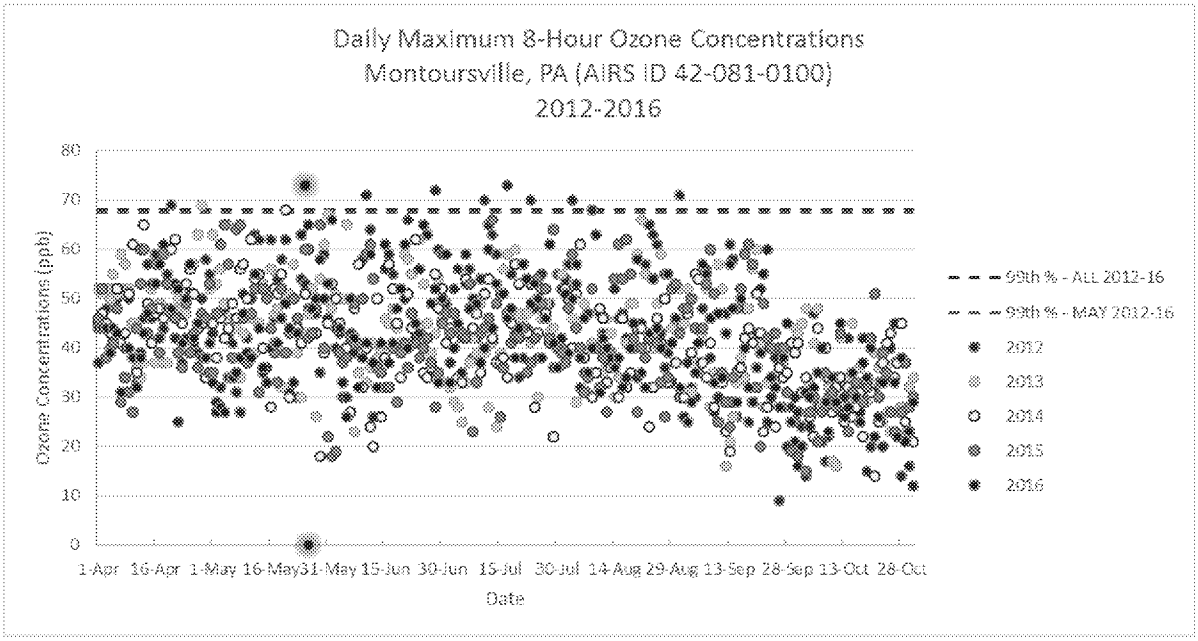


Figure A-32 – Farrell, PA Daily Ozone Season Maximums (2012-2016)

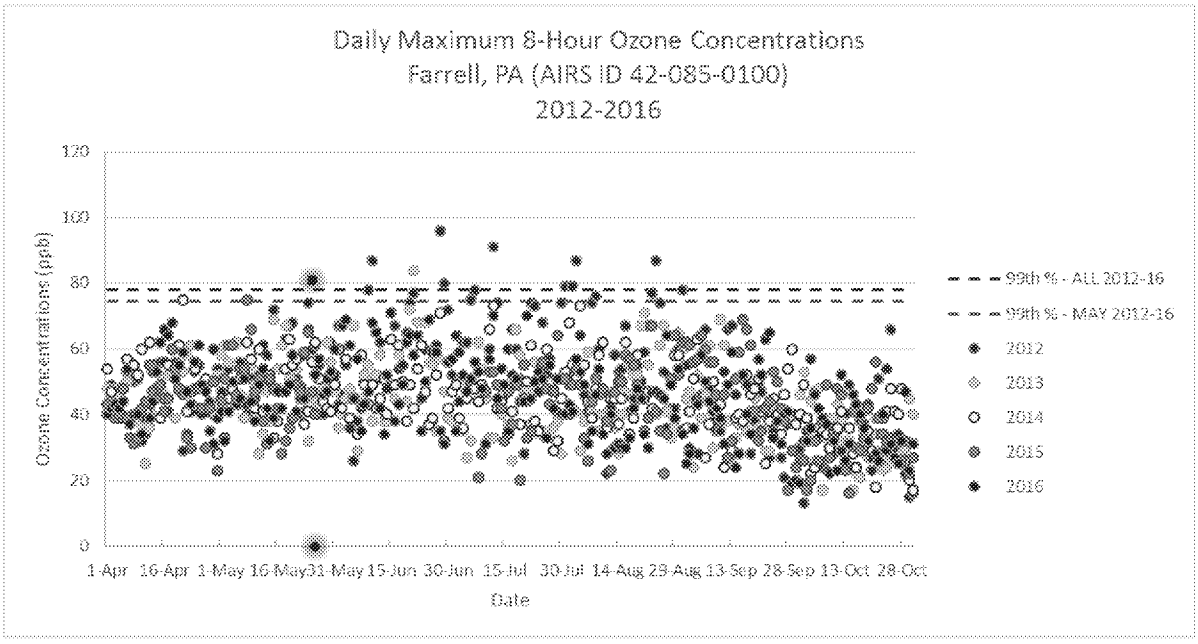


Figure A-33 – Swiftwater, PA Daily Ozone Season Maximums (2012-2016)

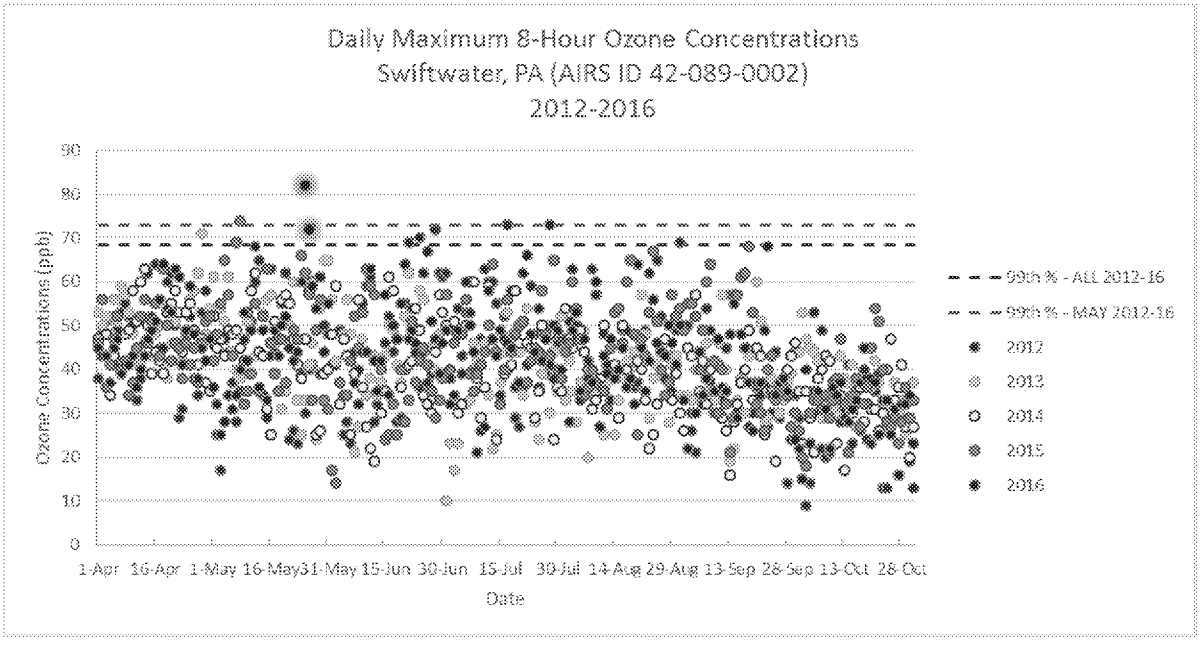


Figure A-34 – Freemansburg, PA Daily Ozone Season Maximums (2012-2016)

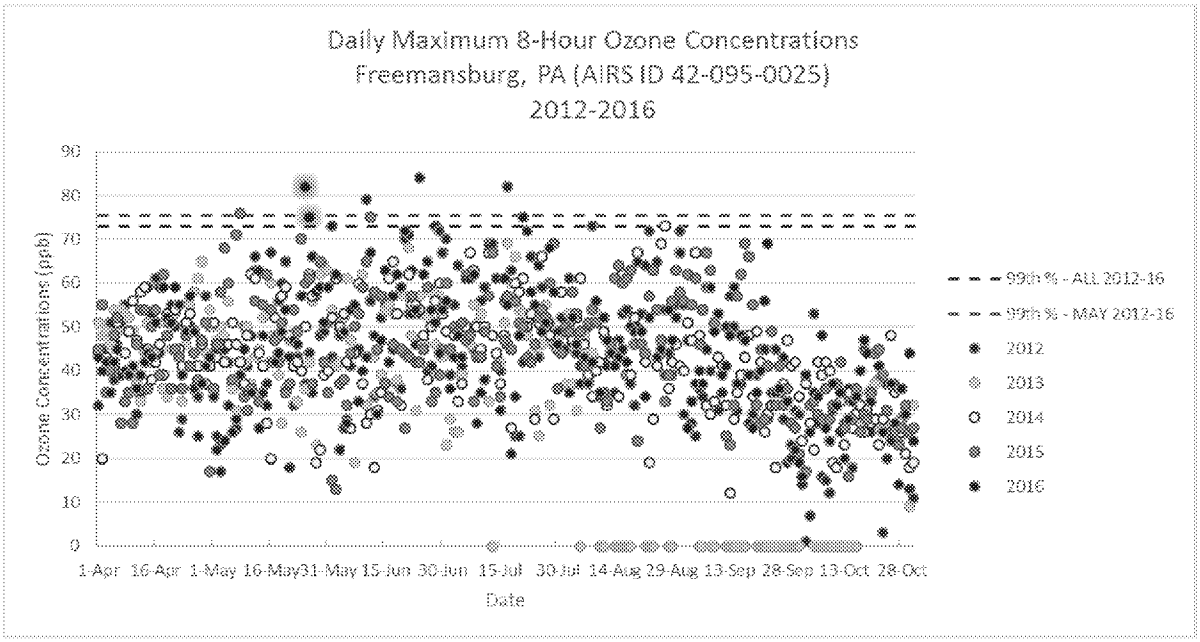


Figure A-35 – Easton, PA Daily Ozone Season Maximums (2012-2016)

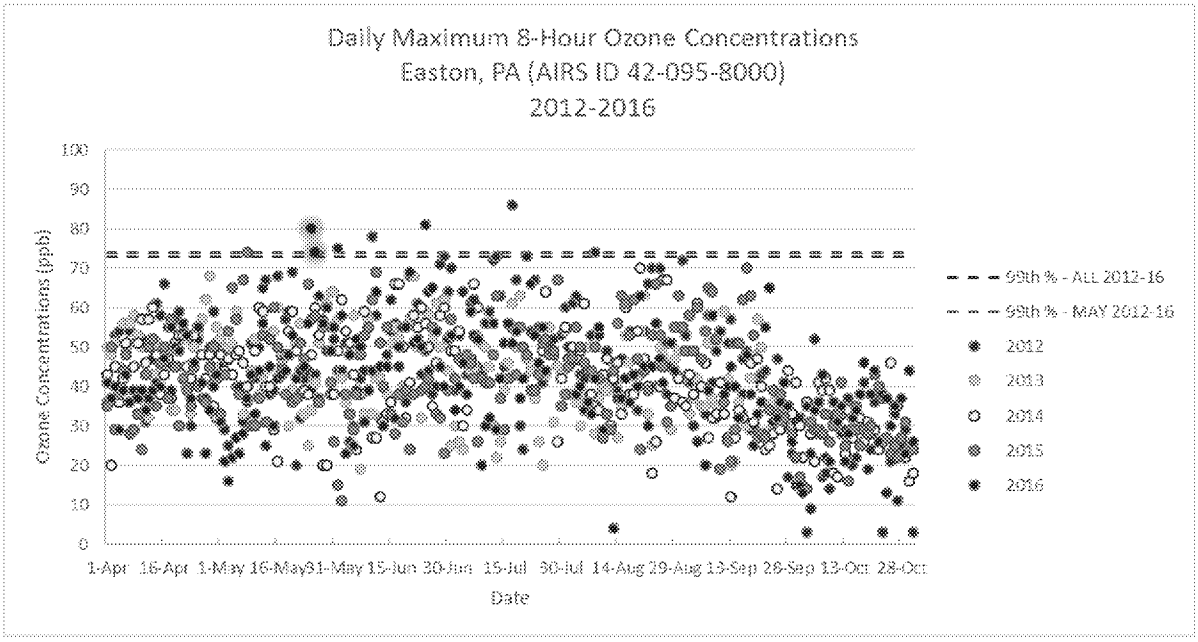


Figure A-36 – AMS Laboratory, Philadelphia, PA Daily Ozone Season Maximums (2012-2016)

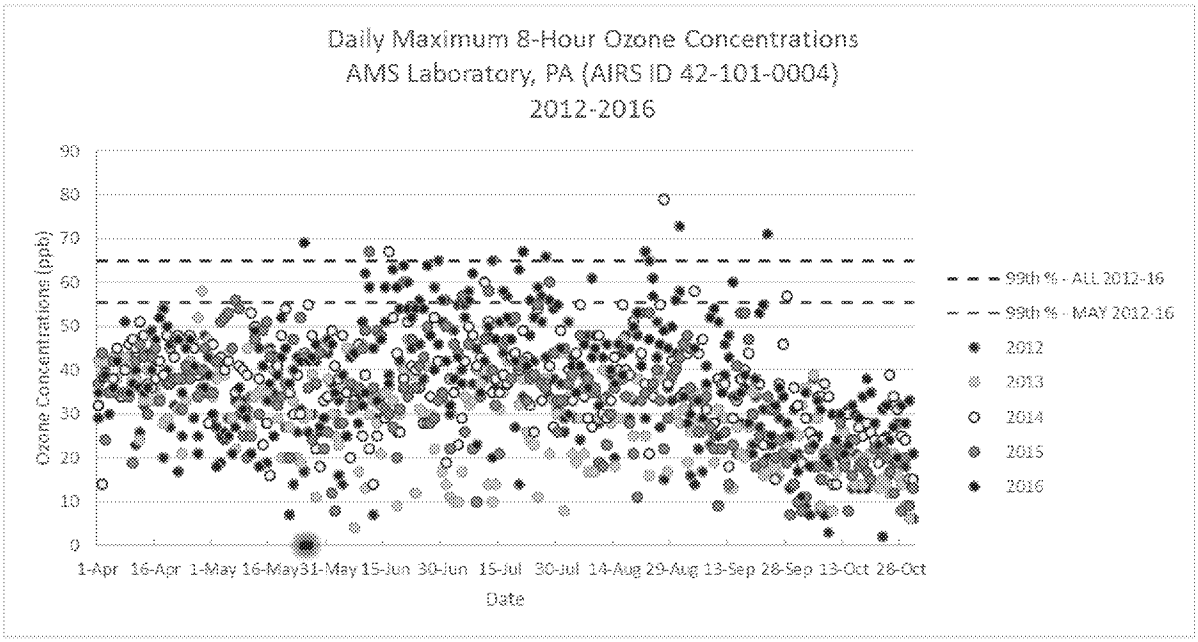


Figure A-37 – Northeast Airport, Philadelphia, PA Daily Ozone Season Maximums (2012-2016)

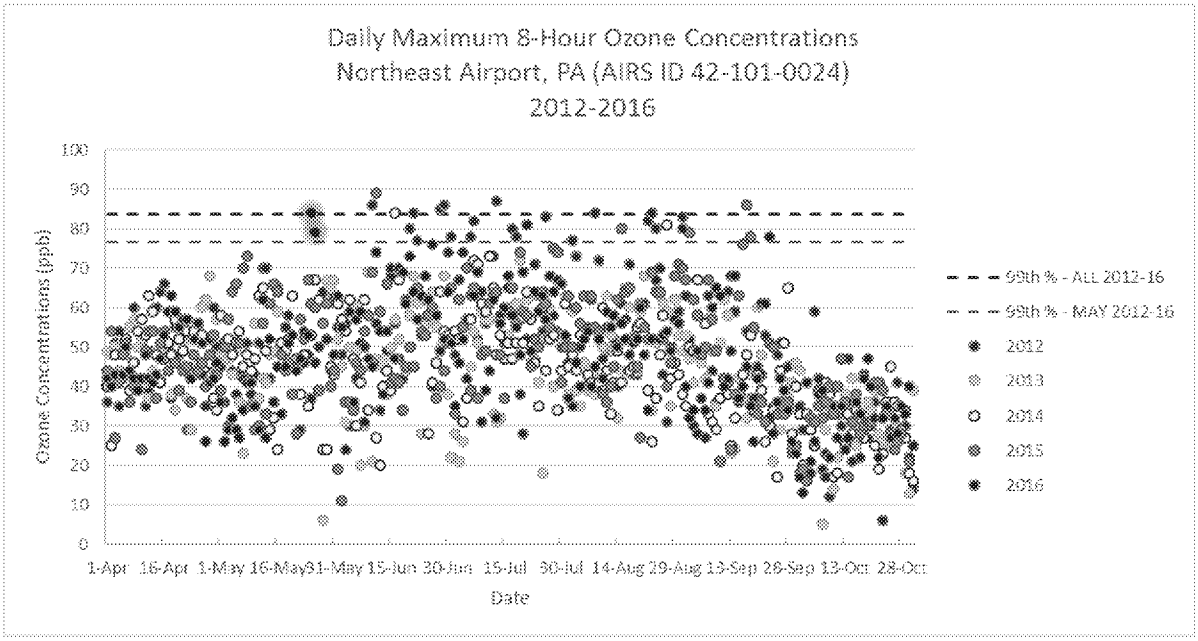


Figure A-38 – Northeast Waste, Philadelphia, PA Daily Ozone Season Maximums (2012-2016)

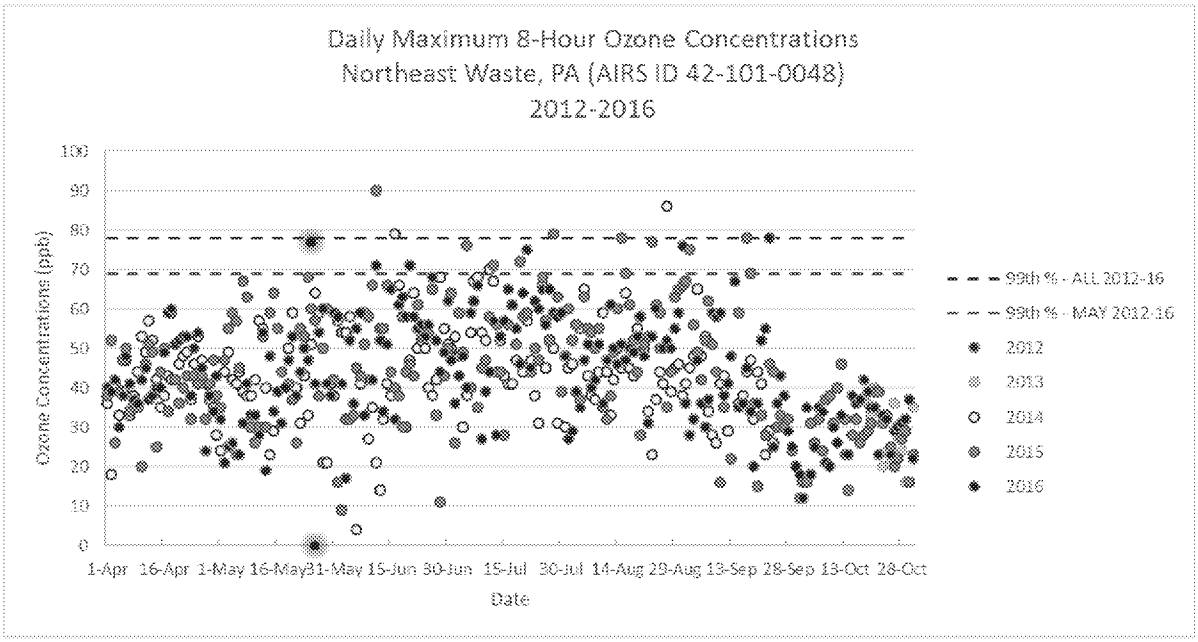


Figure A-39 – Tioga County, PA Daily Ozone Season Maximums (2012-2016)

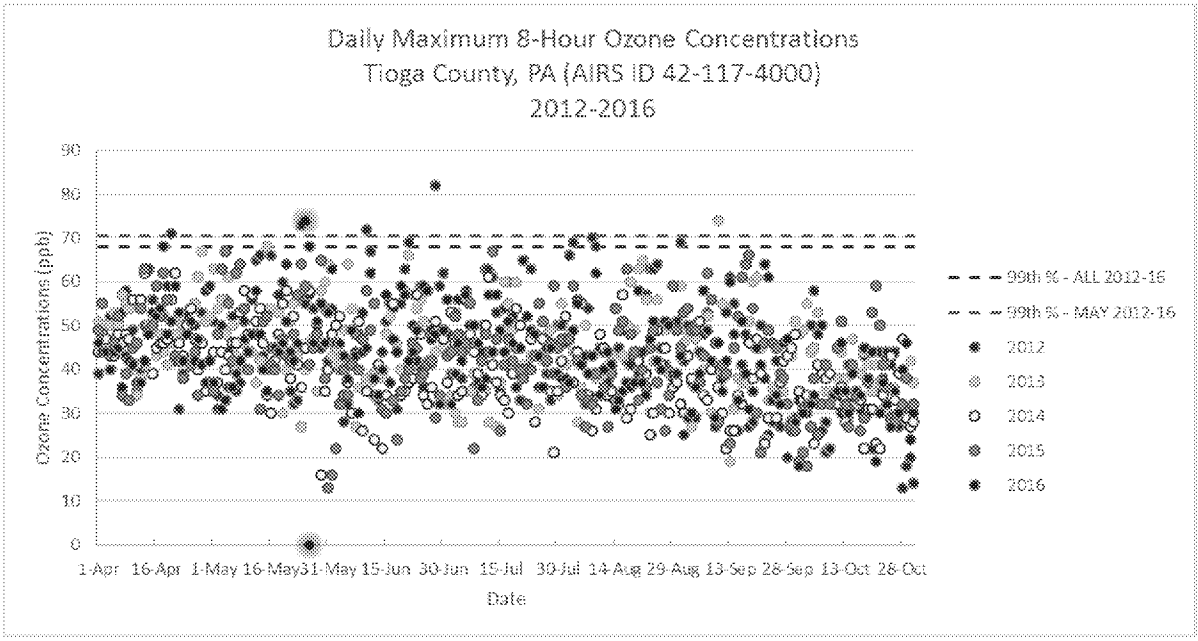


Figure A-40 – Washington, PA Daily Ozone Season Maximums (2012-2016)

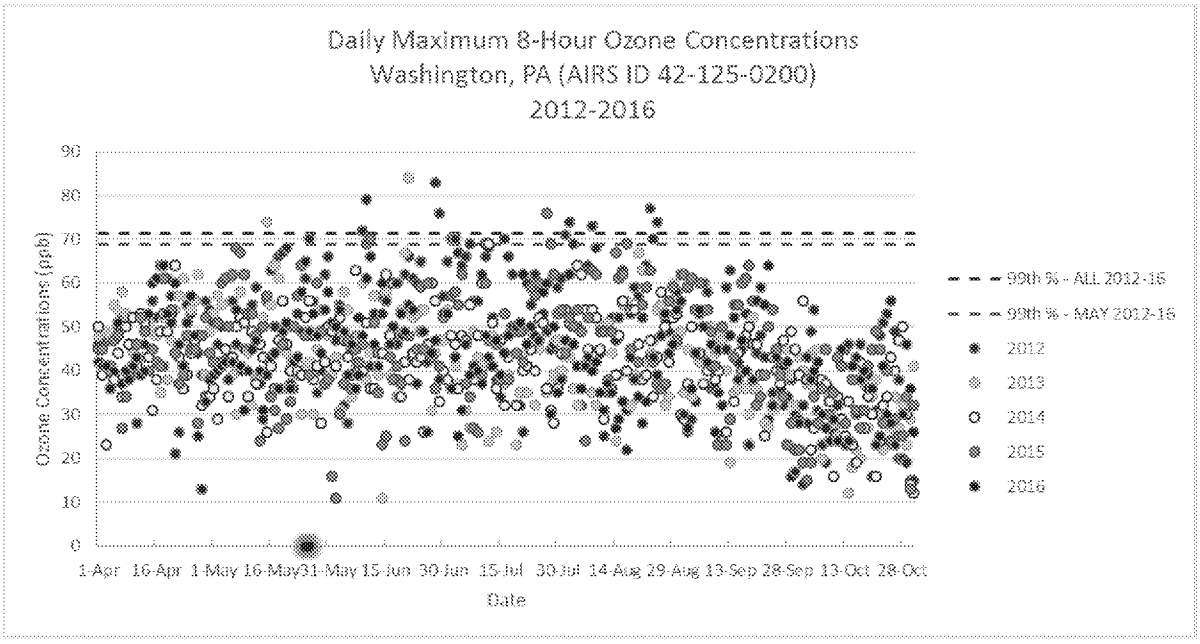


Figure A-41 – Florence, PA Daily Ozone Season Maximums (2012-2016)

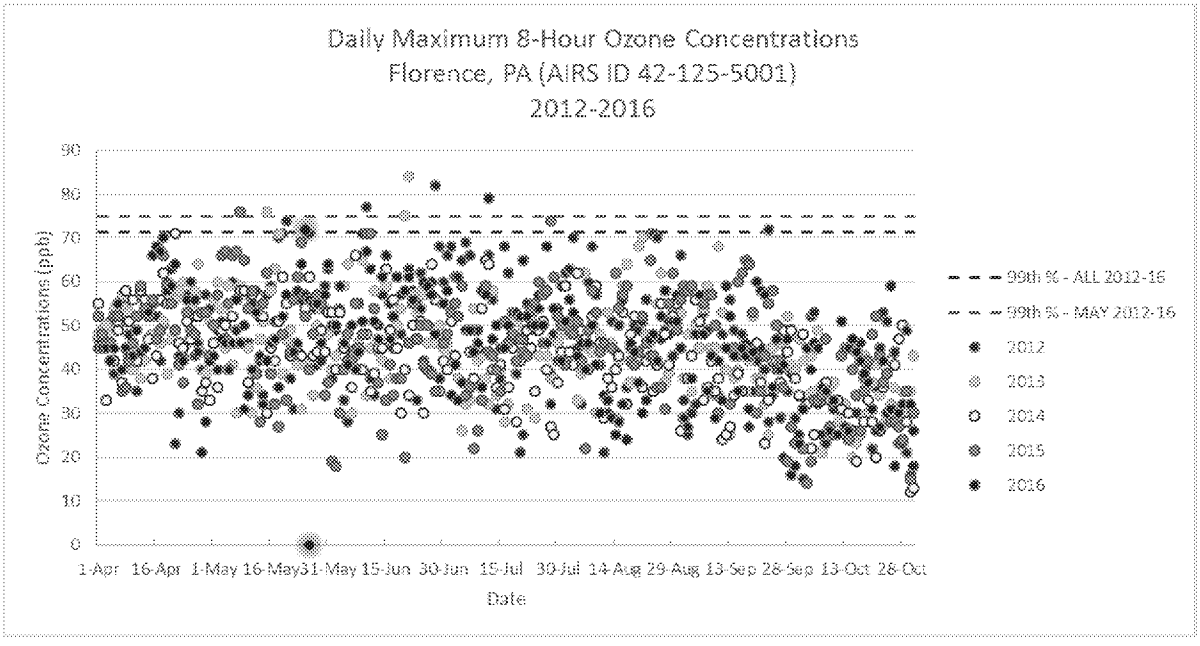


Figure A-42 – York, PA Daily Ozone Season Maximums (2012-2016)

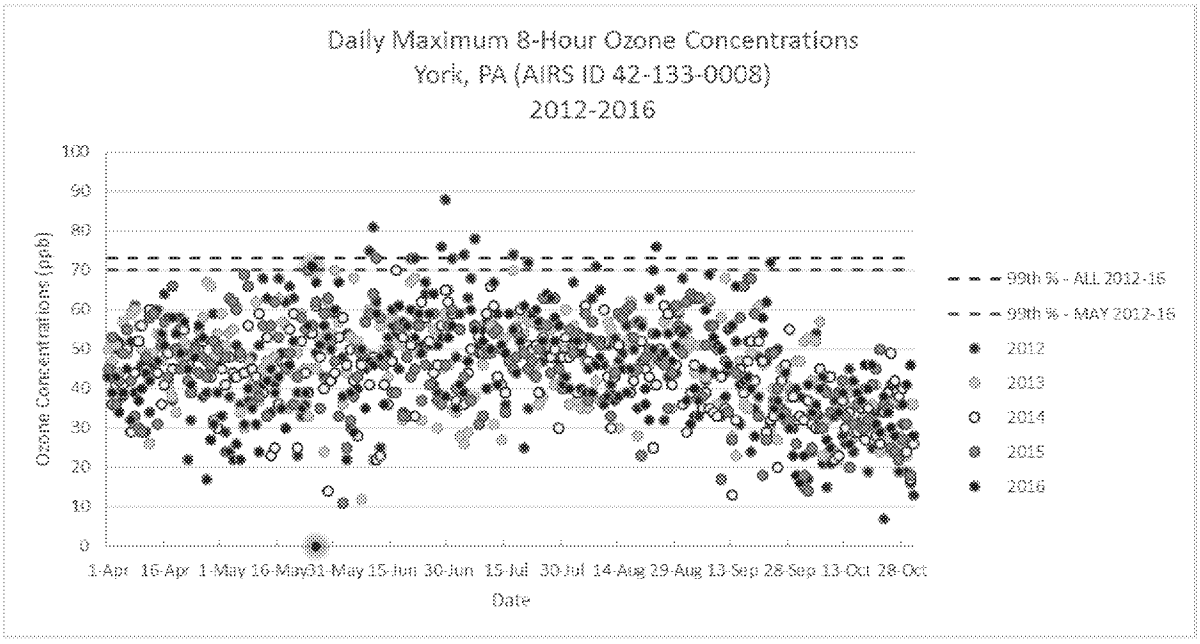


Figure A-43 – York Downwind, PA Daily Ozone Season Maximums (2012-2016)